NOLTR 71-110

BOTTOM REFLECTION OF UNDERWATER EXPLOSION SHOCK WAVES, COMPUTER PROGRAM

By
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30 JULY 1971

NOL

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NOLTR 71-110

109

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ordnance Laboratory, White Oak, Silver Spring, Md 20910	2a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED; 2b. GROUP

3. REPORT TITLE

Bottom Reflection of Underwater Explosion Shock Waves, Computer Program

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

James R. Britt
Hans G. Snay

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 July 1971	100 + vi	6

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. DNA-NA 002-20 P.106	NOLTR 71-110
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; Distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Defense Nuclear Agency

13. ABSTRACT

This report describes a FORTRAN IV computer code, BOTREF, which calculates the bottom reflection pressure history of underwater explosion shock waves. The reflection is computed for incident exponential pulses and plane, homogeneous, elastic bottoms using a linear spherical wave theory. Corrections for the non-linear variations of the peak pressure and time constant with distance are included. The program generates a plot tape for use on CALCOMP incremental plotters. Provisions are made for incorporation of the machine program that calculates the peak translational velocity of a ship target described in NOLTR 71-65. For comparison, an option is included for calculating the bottom reflection using the plane wave theory instead of that for spherical waves.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Explosions						
Nuclear Explosions						
Shock Waves						
Bottom Reflection of Shock Waves						
Cagniard's Method						
Computer Code						

DD FORM 1 NOV 65 1473 (BACK)

(PAGE 2)

UNCLASSIFIED

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ABSTRACT: This report describes a FORTRAN IV computer code, BOTREF, which calculates the bottom reflection pressure history of underwater explosion shock waves. The reflection is computed for incident exponential pulses and plane, homogeneous, elastic bottoms using a linear spherical wave theory. Corrections for the non-linear variations of the peak pressure and time constant with distance are included. The program generates a plot tape for use on CALCOMP incremental plotters. Provisions are made for incorporation of the machine program that calculates the peak translational velocity of a ship target described in NOLTR 71-65. For comparison, an option is included for calculating the bottom reflection using the plane wave theory instead of that for spherical waves.

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BOTTOM REFLECTION OF UNDERWATER EXPLOSION SHOCK WAVES, COMPUTER PROGRAM

This report is part of a continuing study of the interaction of the underwater explosion shock wave with the ocean bottom. The computer program described in this paper calculates the bottom reflection and generates plots of the pressure history. The calculations of this program are being used in the bottom reflection study to assess the potential danger to ships delivering nuclear underwater weapons posed by various bottom materials.

Thanks are due Dr. A. H. Van Tuyl (NOL, Code 331) for his help and valuable advice in the early phases of this work.

This study was supported by the Defense Nuclear Agency through Task DNA-NA (formerly DASA-NA) 002-20 P.106 (Energy Focussing and Reflection Effects).

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By direction

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1. INTRODUCTION

The bottom reflection of the underwater explosion shock wave is of interest to the Navy because of the danger it presents for self-damage to ships delivering nuclear ASW weapons. The theory presently being used to describe the reflection is a linear spherical wave theory originally developed by L. Cagniard (1) for the calculation of the reflection at an interface between two elastic solids. On the basis of Cagniard's theory, Rosenbaum (2) derived equations which describe the bottom reflection of underwater explosion shock waves. Britt (3) has greatly extended and generalized Rosenbaum's work. Britt's report should be consulted when using the computer program described here.

This report describes a computer program, BOTREF, written in FORTRAN IV for the NOL CDC 6400 computer. The code calculates the pressure history of the bottom reflection of incident exponential pulses reflected from plane, homogeneous, elastic bottoms using the spherical wave theory. Major portions of this program were written by the second author. The first author later brought this program into its present versatile form and used it successfully in practical applications.

The program has options for calculating the spherical wave reflection in two ways: (1) using real arithmetic and equations derived using contour integration (referred to as the Cagniard-Rosenbaum method) and (2) using the "complex arithmetic method". The first method is generally faster, but both usually take less than 30 seconds of central processor time on the CDC 6400 for calculating a complete pressure history. Also included in the program is an option for calculating the bottom reflection using the plane wave theory of Arons and Yennie (4). For both the plane wave and the spherical wave, the calculations include corrections for the non-linear changes of the shock wave peak pressure and time constant with the distance from the charge.

The code generates a CALCOMP plot tape of the total pressure history including the incident, bottom reflected, and acoustic surface reflected waves. The print out, in addition to the pressure history, includes information such as the incident angle, the plane wave reflection coefficient and phase shift, critical angles, arrival times, impulses, and energy flux.

The output of the bottom reflection program can be directly transferred to the PTV Program (NOLTR 71-65) which is then used as a subroutine. This program calculates the peak translational velocity (PTV) of a cylindrical target. This velocity can be used as an index for damage.

The equations used in the BOTREF code are described in Section 2 and references are made as to the location in the program where each equation is used. In Section 3 a detailed description is given of the program organization, inputs, outputs, and other important

symbols. The appendices contain a complete FORTRAN listing of the program, sample output, and a CALCOMP plot.

The code contains many comment cards so that most of the inputs and outputs and much of the organization is explained in the program listing.

Comments on Terminology. In the acoustic literature reflectors are called either solids or fluids, depending on whether they have a shear-strength or not. We prefer the terms non-rigid or rigid, because some solids, for instance, sand, have such a low shear strength that the theory for a non-rigid bottom yields sufficiently accurate results, in spite of the fact that the material is a solid. We hope that our terminology will lead to less misunderstandings than the conventional one or the previously used term "liquid bottom".

Rigidity should be understood as the resistance of a body to a change in shape at constant volume. It is equivalent to shear strength and is measured either by the Poisson Ratio or, as in this paper, by the propagation velocity of the shear wave. The shear velocity is zero for a non-rigid material. Compressibility is the resistance to a change in volume at constant shape and can be represented by the propagation velocity of a compression wave, i.e., the sound velocity.

The word rigid often has the connotation of a material having infinite rigidity. We use it in the sense of a material having a finite, non-vanishing rigidity.

2. THEORY USED TO CALCULATE THE BOTTOM REFLECTION

2.1 Theory of the Bottom Reflection of a Spherical Wave

The theory used in the computer program described in this report has been derived by Rosenbaum (2). Britt (3) has reviewed, explained, and greatly extended Rosenbaum's work. A semi-linear theory is used which describes all phenomena of interest with adequate accuracy. The notation used in this section is essentially that of Britt's report. The following exceptions are to be noted. We denote the excess pressure by p instead of P. Britt and Rosenbaum denote the time by τ; we use t for the time and τ_m for Rosenbaum's reduced time (compare with Equation (2.2.2)). The program calculates the step wave response ${}_nP_m = {}_1P_1$ which corresponds to one reflection from the bottom. Multiple reflections between the surface and the bottom are not included. (Multiple reflections are of minor importance to underwater explosion phenomena that lead to damage processes. When a strong pressure wave is reflected at the water surface, most of the wave energy is left near the surface and does not propagate down into the water because of cavitation and spray formation.)

We denote ${}_1P_1$ by P_r, the bottom reflection slant range ${}_1R_1$ by R_r, the incident or direct wave range by R_i, and the surface reflection range by R_s. We also drop the subscripts n and m except in τ_m and K_m (Equation 2.2.18).

The geometry of the bottom reflection is shown in Figure 1. The water depth is H. The depths of the charge and gauge are d and d_g. The horizontal distance between charge and gauge is r. The incident angle of the bottom reflection is θ. From this figure

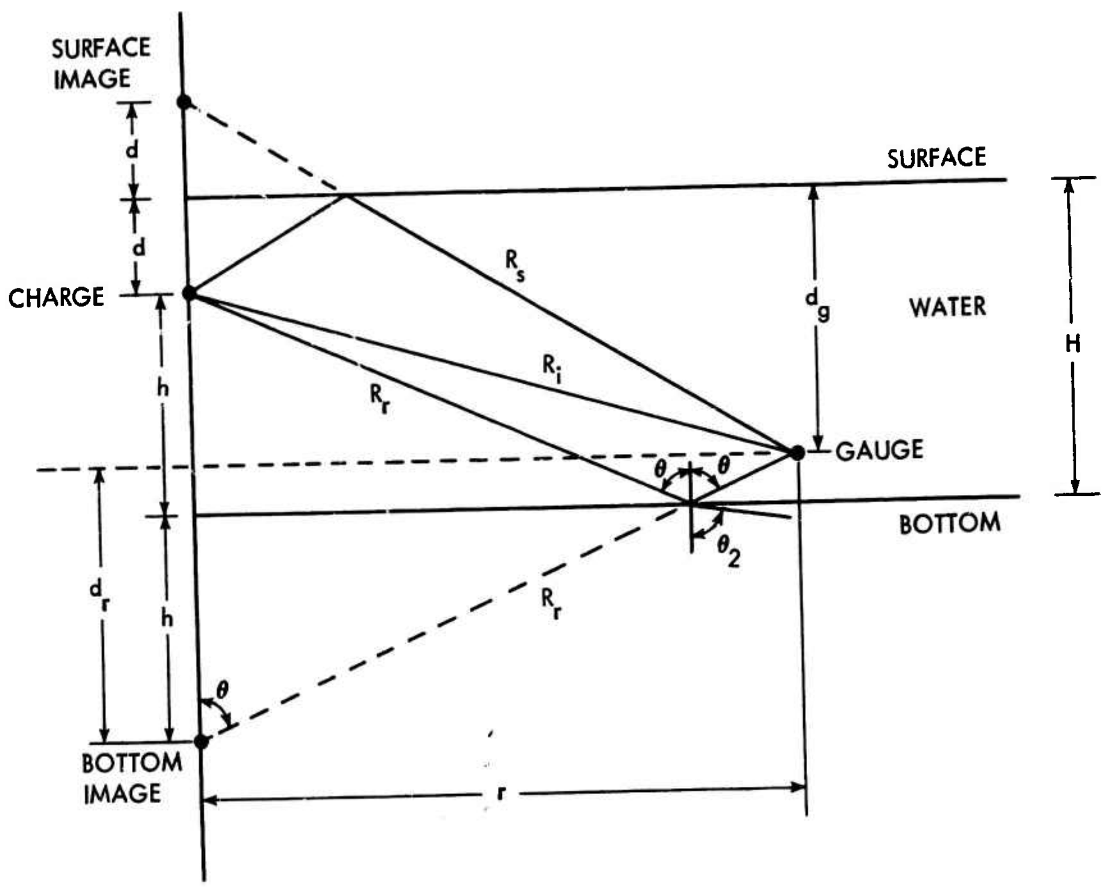

FIG. 1 BOTTOM REFLECTION GEOMETRY

we see that the slant ranges are given by the equations

$$R_i = \left[(d - d_g)^2 + r^2\right]^{1/2} \quad \text{(slant range of incident wave)} \qquad (2.1.1)$$

$$R_r = \left[d_r^2 + r^2\right]^{1/2} \quad \text{(slant range of wave reflected at bottom)} \qquad (2.1.2)$$

and

$$R_s = \left[(d_g + d)^2 + r^2\right]^{1/2} \quad \text{(slant range of the wave reflected at the water surface),} \qquad (2.1.3)$$

where $d_r = 2H - d_g - d$ is the depth of the "image" below the gauge. Further, we have

$$\cos\theta = d_r/R_r \qquad (2.1.4)$$

and

$$\sin\theta = r/R_r. \qquad (2.1.5)$$

In the water the sound velocity is denoted by c_1, and the density by ρ_1. Similarly, the sound velocity in the bottom material is c_2, the shear wave propagation velocity is c_4, and the density is ρ_2. (Britt denoted the sound velocity and density of a rigid bottom by c_3 and ρ_3.)

2.1.1 Critical Angles. For an incident angle θ, which is also the reflected angle, the refracted or transmitted ray into the bottom makes an angle θ_2 (see Figure 1) given by Snell's law

$$\sin\theta = \frac{c_1}{c_2}\sin\theta_2. \qquad (2.1.6)$$

The angle θ_2 is that angle at which the pressure wave enters the bottom. Similarly, the angle θ_4 of the shear wave in the bottom is defined

$$\sin\theta = \frac{c_1}{c_4}\sin\theta_4. \qquad (2.1.7)$$

When $c_2 > c_1$ or $c_4 > c_1$ the angles θ_2 and θ_4 become 90° at incident angles θ_{cr} and θ_{crs} defined by

$$\sin \theta_{cr} = c_1/c_2 \tag{2.1.8}$$

$$\sin \theta_{crs} = c_1/c_4. \tag{2.1.9}$$

θ_{cr} is called the critical angle of the compression wave, and θ_{crs} is called the critical angle of the shear wave. These angles are important for calculating and interpreting the bottom reflection pressure history.

2.1.2 <u>The Incident Pulse</u>. The computer program assumes an exponential incident pulse $p_i(t)$ given by

$$\begin{aligned} p_i(t) &= p_F(R_i) \exp\left[-(t - R_i/c_1)/G\right] && \text{for } t \geq R_i/c_1 \\ p_i(t) &= 0 && \text{for } t < R_i/c_1, \end{aligned} \tag{2.1.10}$$

where G is the time constant (usually denoted by θ) and $p_F = p_F(R_i)$ is the peak pressure of the incident shock wave. A reduced notation is used in the machine program utilizing the incident slant range R_i (Equation 2.1.1) as the characteristic length. The reduced time is $\bar{t} = tc_1/R_i$. (It is denoted by T in the program). The reduced arrival time of the front of the direct wave is thus $\bar{t} = 1$. The incident pulse is then given by

$$\begin{aligned} p_i(\bar{t}) &= p_F(R_i) \exp\left[-(\bar{t} - 1)/\bar{G}\right] && \text{for } \bar{t} \geq 1 \\ p_i(\bar{t}) &= 0 && \text{for } \bar{t} < 1, \end{aligned} \tag{2.1.11}$$

where $\bar{G} = c_1 G/R_i$ is the reduced time constant.

For the time constant G and the peak pressure p_F the relations for the actual underwater explosion shock waves (high amplitude waves) are used which when used together with the wave equation comprise the "semi-linear" theory. The shock wave parameters are obtained from the similitude equations

$$G = C_G\, W^{1/3}\, (W^{1/3}/R_i)^{n_G} \tag{2.1.12}$$

$$p_F = C_p (W^{1/3}/R_i)^{n_p}\ , \tag{2.1.13}$$

where C_G, C_p, n_G, and n_p are constants for a given explosive. W is the charge weight in pounds, or, with appropriate constants, the yield in kilotons. G and p_F are calculated in the main program in Cards BOTR160-167.

Examples of the constants are

Explosive	C_p	n_p	C_G	n_G
TNT	21600	1.13	0.052	-0.23
HBX-1	23800	1.15	0.049	-0.29
Nuclear (W = Yield in kt)	$4.291 \cdot 10^6$	1.13	2.242	-0.22
	$4.380 \cdot 10^6$	1.13	2.274	-0.22

The values for nuclear explosions of the upper row are the most recent ones. Those in the lower row are generally quoted in the literature. The constants C_p and C_G are given in psi and milliseconds.

2.1.3 <u>The Surface Reflection.</u> The surface reflection $p_s(t)$ calculated from the simple acoustic equation is

$$\begin{aligned} p_s(t) &= -p_F(R_s)\ \exp\left[-(t - R_s/c_1)/G_s\right] && \text{for } t \geq R_s/c_1 \\ p_s(t) &= 0 && \text{for } t < R_s/c_1\ , \end{aligned} \tag{2.1.14}$$

where $G_s = G(R_s)$. In reduced notation this becomes

$$p_s(\bar{t}) = -p_F(R_s) \quad \exp\left[-(\bar{t} - \bar{R}_s)/\bar{G}_s\right] \quad \text{for } \bar{t} \geq \bar{R}_s$$
$$p_s(\bar{t}) = 0 \qquad \text{for } \bar{t} < \bar{R}_s, \qquad (2.1.15)$$

where $\bar{G}_s = c_1 G_s/R_i$ and $\bar{R}_s = R_s/R_i$. These equations are coded in Cards BOTR218, 704, and 882.

The surface reflection is a tension wave and its pressure is to be subtracted from the pressure of the incident and the bottom reflected wave.

Equations (2.1.14 and 15) ignore cavitation which in sea water does not let pressures drop substantially below the vapor pressure. In the machine program this is taken into account by a test that makes sure that the total pressure does not fall below zero absolute (Cards BOTR713 and 884).

For a very oblique incidence the acoustic treatment of the surface reflection breaks down and must be replaced by the anomalous surface reflection described in NOLTR 70-31. The machine program described here does not include this mode of the surface reflection. This problem will be treated in another machine program that describes the shock wave propagation in shallow water.

2.1.4 The Convolution Integral. The theory of the bottom reflection yields the reflected wave for an incident step wave. This step wave response, denoted by $P_r(t)$, is the crucial point of the analysis and will be discussed in detail later. It has the dimension of $(\text{Length})^{-1}$. The pressure history of the bottom reflected wave for an exponential incident wave $p_r(t)$ is obtained from the convolution integral:

$$p_r(t) = p_F'(R_r)\left[P_r(t) - 1/G_r \int_{\delta}^{t} \exp\left[-(t - z)/G_r\right] P_r(z)\,dz\right] \quad \text{for } t \geq \delta$$

$$p_r(t) = 0 \quad \text{for } t < \delta . \qquad (2.1.16)$$

This equation is explained in Appendix D of Britt's report. The scale factor p_F' and the time constant G_r are given by

$$p_F' = R_r p_F(R_r) \qquad (2.1.17)$$

$$G_r = G(R_r), \qquad (2.1.18)$$

where R_r is the slant range of the reflected wave, Equation (2.1.2). The factor R_r of the reduced pressure scale factor p_F' stems from the definition of the reduced step wave response $P_r(t)$ which includes R_r^{-1} as a factor.

The reduced form of the convolution integral is readily obtained by introduction of $\bar{t} = tc_1/R_i$, $\bar{\delta}$, $\bar{z}$, and $\bar{G}_r = c_1 G_r/R_i$.

The symbol δ in Equation (2.1.16) denotes the arrival time of the bottom reflection.

For subcritical incidence, $\theta < \theta_{cr}$, we have

$$\delta = t_c = R_r/c_1 \qquad (2.1.19)$$

and the reduced form is

$$\bar{\delta} = c_1 \delta/R_i = R_r/R_i . \qquad (2.1.20)$$

In this case δ is the arrival time t_c of the peak of the reflected wave.

For supercritical incidence, $\theta > \theta_{cr}$, the precursor of the bottom reflection arrives before $t = t_c$, namely at

$$\delta = r/c_2 + d_r(c_1^{-2} - c_2^{-2})^{1/2} \qquad (2.1.21)$$

or in the dimensionless form

$$\bar{\delta} = rc_1/c_2R_i + d_r\left[1 - (c_1/c_2)^2\right]^{1/2}/R_i. \qquad (2.1.22)$$

The convolution integral is calculated in the BOTREF program Cards BOTR556, 589, 597, 635, 643, and 673 using Simpson's rule for small intervals with three equally spaced points.

For an exponential incident pulse the integral need not be recalculated from $t = \delta$ for each time step because of

$$\exp(t + \Delta t) = \exp(t)\exp(\Delta t).$$

The algorithm used to calculate the integral in Equation (2.1.16), which we call F_I, is as follows:

$$F_I(t) = \exp(-2\Delta t/G_r)F_I(t - 2\Delta t) + \left\{\left[P_r(t - 2\Delta t)\exp(-\Delta t/G_r) + 4P_r(t - \Delta t)\right]\exp(-\Delta t/G_r) + P_r(t)\right\}\Delta t/3 . \qquad (2.1.23)$$

This relation permits a convenient step-by-step quadrature of the integral using its value for a time $2\Delta t$ earlier. The expression is readily transformed into a reduced form by the introduction of $\bar{t}$, $\Delta\bar{t}$, and $\bar{G}_r$. F_I has the dimension time/length.

For supercritical incidence $P_r(t)$ has a logarithmic singularity at $t = t_c$. Since $P_r(t)$ is a rapidly changing function of t near t_c, a smaller time increment, $\Delta t' \approx \Delta t/8$, is used in the code for the interval $(t_c - \alpha\Delta t,\ t_c + 4\Delta t)$. The code calculates α so that there are enough points in the bottom reflection pressure-time history (before and after the time increment change) to execute the impulse

and energy flux integrations. The usual range is $2.1 < \alpha < 6.1$. Because these integrations are performed with Simpson's rule on equally spaced points, each integration step is completed on an odd-numbered point.

Further, in the time range $t_c - 2\Delta t' < t < t_c + 2\Delta t'$ we change the integration variable in the convolution integral F_I to

$$v^2 = t_c^2 - z^2 \qquad \text{for } z \le t_c$$

$$u^2 = z^2 - t_c^2 \qquad \text{for } z \ge t_c.$$

The step wave response $P_r(t)$ behaves near the singularity like

$$\lim_{t \to t_c} P_r(t) = C \ln(\,|\,t_c - t\,|\,).$$

The change of variables v and u transforms the last two factors of Equation (2.1.16) as follows:

$$P_r(z)\ dz = -\frac{v}{z} P_r(z)\ dv \qquad z \le t_c$$

$$= \frac{u}{z} P_r(z)\ du \qquad z \ge t_c.$$

Then we obtain

$$\lim_{z \to t_c} -\frac{v}{z} P_r(z) = -C \lim_{z \to t_c} \frac{(t_c^2 - z^2)^{1/2}}{z} \ln(t_c - z) = 0 \qquad z \le t_c$$

$$\lim_{z \to t_c} \frac{u}{z} P_r(z) = C \lim_{z \to t_c} \frac{(z^2 - t_c^2)^{1/2}}{z} \ln(z - t_c) = 0 \qquad z \ge t_c.$$

This means the integrands vanish at the singularity of P_r, and thus makes numerical integration possible.

Equation (2.1.24) below illustrates the variable change.

$$p_r(t) = p_F' \Bigg[P_r(t) - \frac{1}{G_r}\Bigg\{ \int_{\delta}^{t_c - 2\Delta t'} \exp\Big[-(t - z)/G_r\Big] P_r(z)\, dz$$

$$- \int_{v(t_c - 2\Delta t')}^{v(t_c)} \exp\Big[-(t - z)/G_r\Big] P_r(z) \frac{v}{z}\, dv$$

$$+ \int_{u(t_c)}^{u(t_c + 2\Delta t')} \exp\Big[-(t - z)/G_r\Big] P_r(z) \frac{u}{z}\, du$$

$$+ \int_{t_c + 2\Delta t'}^{t} \exp\Big[-(t - z)/G_r\Big] P_r(z)\, dz \Bigg\}\Bigg]. \qquad (2.1.24)$$

Up to time $t_c - 2\Delta t'$ and after time $t_c + 2\Delta t'$ the integration variable is z and the algorithm of Equation (2.1.23) is used to perform the quadrature. Around the singularity Simpson's rule on equally spaced intervals of v and u, instead of z or time, is used for the integration.

Using the algorithms described below, $F_I(t)$ and $p_r(t)$ are evaluated in two steps before and after the singularity. When $t_c - 2\Delta t' < t \le t_c$, the following variables are used:

$$t_1 = t_c - 2\Delta t' \qquad (2.1.25)$$

$$v_1 = v(t_1) = (t_c^2 - t_1^2)^{1/2} \qquad (2.1.26)$$

$$t_2 = \left[t_c^2 - (3v_1/4)^2\right]^{1/2} \qquad (2.1.27)$$

$$t_3 = \left[t_c^2 - (v_1/2)^2\right]^{1/2} \qquad (2.1.28)$$

$$t_4 = [t_c^2 - (v_1/4)^2]^{1/2} \quad (2.1.29)$$

The fifth time used here is t_c. However, $P_r(t_c)$ does not appear in the equations for F_I because the transformed integrand vanishes. The value of F_I at $t = t_3$ is obtained from

$$F_I(t_3) = F_I(t_1)\exp[-(t_3-t_1)/G_r] + \{P_r(t_1)\exp[-(t_3-t_1)/G_r]v_1/t_1 + 3P_r(t_2)\exp[-(t_3-t_2)/G_r]v_1/t_2 + P_r(t_3)v_1/2t_3\} v_1/12 \, . \quad (2.1.30)$$

This equation is coded in reduced notation in Card BOTR589. For the next step $F_I(t_c)$ is calculated using

$$F_I(t_c) = F_I(t_3)\exp[-(t_c-t_3)/G_r]+\{ P_r(t_3)\exp[-(t_c-t_3)/G_r]v_1/2t_3 + P_r(t_4) \exp[-(t_c-t_4)/G_r] v_1/t_4\} v_1/12 \, . \quad (2.1.31)$$

This equation is coded in reduced notation (Card BOTR597).

Similarly, after the singularity we define the following variables:

$$t_5 = t_c + 2\Delta t' \quad (2.1.32)$$

$$u_1 = u(t_5) = (t_5^2 - t_c^2)^{1/2} \quad (2.1.33)$$

$$t_2 = [t_c^2 + (u_1/4)^2]^{1/2} \quad (2.1.34)$$

$$t_3 = [t_c^2 + (u_1/2)^2]^{1/2} \quad (2.1.35)$$

$$t_4 = [t_c^2 + (3u_1/4)^2]^{1/2} . \quad (2.1.36)$$

Here t_1 is the time of the singularity t_c, but $P_r(t_c)$ is not needed

since the transformed integrand vanishes. The value of $F_I(t_3)$ is then given by

$$F_I(t_3) = F_I(t_c)\exp[-(t_3-t_c)/G_r] + \{P_r(t_2)u_1\exp[-(t_3-t_2)/G_r]/t_2$$

$$+ P_r(t_3)u_1/2t_3\}u_1/12 \,. \qquad (2.1.37)$$

This equation is converted to reduced notation and coded in Card BOTR635. Then the last step using the special integration variables is

$$F_I(t_5) = F_I(t_3)\exp[-(t_5-t_3)/G_r] + \{P_r(t_3)u_1\exp[-(t_5-t_3)/G_r]/2t_3$$

$$+ 3P_r(t_4)u_1\exp[-(t_5-t_4)/G_r]/t_4 + P_r(t_5)u_1/t_5\}u_1/12 \,.$$

$$(2.1.38)$$

This equation in reduced form is coded in Card BOTR643.

2.1.5 The Impulse and Energy Flux. The impulse I and energy flux E_F are calculated in the main program Cards BOTR717-766. These calculations are made only if the spherical wave bottom reflection is used. The impulse in psi-sec is evaluated from the equation

$$I = \int_{t_o}^{t} p(t)\,dt,$$

where $p(t) = p_i(t) + p_r(t) + p_s(t)$ is the total pressure of the incident, bottom reflected, and surface reflected waves and t_o is the time of the beginning of the pressure pulse p(t).

The energy flux E_F in in-psi is found from the equation

$$E_F = \left\{ \int_{t_o}^{t} |p| \, p \, dt \right\} / (2.3066 \, \rho_1 c_1) \, ,$$

where 2.3066 is a conversion factor necessary for E_F to be in units in-psi when p is in psi, time in seconds, ρ_1 in gm/cm^3, and c_1 in ft/sec.

Away from the singularity of $p_r(t)$ of $t = t_c$ and for sub-critical bottom reflections the integrals are determined using Simpson's rule on equally spaced points as a function of time. Near the singularity the change of integration variables is made to v and u as for the convolution integral. This change of variables is made in Cards BOTR738-755.

Also calculated in the same section of the program is the "positive impulse" which is simply the impulse of the positive part of the total pressure p(t). If the full output option is used (see the input Z5 in Section 3.1 and the sample outputs of Appendix B), the magnitudes reduced impulse $I/W^{1/3}$, reduced positive impulse, and reduced energy flux $E_F/W^{1/3}$ are calculated in Cards BOTR793-797.

2.2 The Cagniard-Rosenbaum Method for Calculating the Step Wave Response

In this section the Cagniard-Rosenbaum equations are listed, and forms of these equations similar to the FORTRAN notation are given. This method is faster than the complex arithmetic method which will be discussed in Section 2.3, but it has the disadvantage that separate equations are required for the precursor and the main wave and for each type of bottom (determined by the ordering

of c_1, c_2, and c_4). However, in the coding we were able to take advantage of certain common factors and terms and hence reduce the number of statements that would otherwise be required.

2.2.1 Non-Rigid Bottom Precursors. A fast non-rigid bottom ($c_2 > c_1$) for which $\theta > \theta_{cr}$ has a step wave response at times $\delta \leqslant t < t_c$ expressed by the following equation (Britt (2-1.10)):

$$P_r(t) = \frac{b(\sigma - M)}{R_r} \int_{-1}^{1} \frac{\omega(\sigma+\omega)^{1/2}(1-\sin \pi\psi/2)\, d\psi}{[(1-b^2)\omega^2+\sigma^2 b^2](\omega-N)^{1/2}}, \tag{2.2.1}$$

where $\omega = (\sigma + M)/2 + \left[(\sigma - M)/2\right] \sin \pi\psi/2,$ (2.2.2)

$b = \rho_1/\rho_2$, $\tau_m = t/R_r$, $\sigma = (c_1^{-2} - c_2^{-2})^{1/2}$, $M = \tau_m \cos\theta + (c_1^{-2} - \tau_m^2)^{1/2} \sin\theta$, $N = \tau_m \cos\theta - (c_1^{-2} - \tau_m^2)^{1/2} \sin\theta$, $\sin\theta = r/R_r$, and $\cos\theta = d_r/R_r$. In the program the integration variable $x = \pi\psi/2$ is used. We also set $w = c_1\omega$. Then after rearranging, Equation (2.2.1) can be put into the form which is coded

$$R_i P_r(t) = \frac{2\sqrt{2}\, b\, R_i}{\pi R_r} \int_{-\pi/2}^{\pi/2} \frac{F_x\, w\, dx}{w^2+b^2(c_1{}^2\sigma^2 - w^2)}, \tag{2.2.3}$$

where

$$F_x = (1 - \sin x)\left\{\left[(c_1\sigma+w)(c_1\sigma-c_1 M)\right] \Big/ \left[1+\sin x + 4(1-c_1^2\tau_m^2)^{1/2}\sin\theta/(c_1\sigma-c_1 M)\right]\right\}^{1/2}. \tag{2.2.4}$$

$$= (1 - \sin x)\left\{[(\cos\alpha + w)\, P(1)]/[1+\sin x+P(2)]\right\}^{1/2},$$

with $\cos\alpha = c_1\sigma = [1 - (c_1/c_2)^2]^{1/2}$,

$$P(1) = \cos\alpha - c_1 M,$$

$$P(2) = 4(1 - c_1{}^2\tau_m{}^2)^{1/2} \sin\theta/P(1).$$

The variables $\cos\alpha$, $P(1)$, and $P(2)$ are calculated in Cards BOTR238, STPA022, and 23.

The integrand above is evaluated in FUNCTION ONE. The variable F_x is coded in Card ONE023, and the value of the integrand is ONE in Card ONE055. The factor outside the integral is calculated in Card STPA025. The integration for this and all other precursors is controlled by SUBROUTINE STPWA which uses the Gaussian quadrature of FUNCTION FGI to evaluate the integral. The value of $R_i P_r(t)$, called STPW in Card STPA027, is returned to the main program BOTREF where the convolution integral is executed.

2.2.2 Rigid Bottom Precursor, Case $c_2 > c_1 > c_4$. The precursor integrands for a rigid bottom are also evaluated in FUNCTION ONE. For the case $c_2 > c_1 > c_4$ (slow shear) the following equation (Britt (4-1.6)) is used

$$P_r(t) = \frac{b(\sigma-M)}{4R_r c_4{}^4} \int_{-1}^{1} \frac{(\sigma+\omega)^{1/2} A(1-\sin \pi\psi/2)\, d\psi}{(\omega-N)^{1/2}\left[A^2 + (B + C)^2\right]} , \qquad (2.2.5)$$

where

$$A = \omega(c_4^{-2}/2 - c_1^{-2} + \omega^2)^2 \qquad (2.2.6)$$

$$B = \omega(c_1^{-2}-\omega^2)(\sigma^2-\omega^2)^{1/2}\left|\omega^2+c_4^{-2}-c_1^{-2}\right|^{1/2} \qquad (2.2.7)$$

$$C = bc_4^{-4}(\sigma^2-\omega^2)^{1/2}/4 . \qquad (2.2.8)$$

In a manner similar to the non-rigid bottom, Equation (2.2.5) can be rearranged to obtain the program form

$$R_i P_r(t) = \frac{2\sqrt{2}\, b\, R_i}{\pi R_r} \int_{-\pi/2}^{\pi/2} \frac{F_x A_x\, dx}{\left[A_x^2+(B_x+C_x)^2\right]} , \qquad (2.2.9)$$

where $w = c_1\omega$, $\cos\alpha = c_1\sigma$, and

$$A_x = 4c_1c_4{}^4A = w[1-2(c_4/c_1)^2(1-w^2)]^2, \qquad (2.2.10)$$

$$B_x = 4c_1c_4{}^4B = 4w(c_4/c_1)^2(1-w^2)\ [(\cos^2\alpha - w^2)\ |(c_4/c_1)^2(w^2-1)\ +1|]^{1/2}, \qquad (2.2.11)$$

$$C_x = 4c_1c_4{}^4C = b(\cos^2\alpha - w^2)^{1/2}. \qquad (2.2.12)$$

As in the previous case F_x and the factor outside the integral are calculated in Cards ONE023, and STPA025. The variables A_x, B_x, and C_x are coded in Cards ONE043, 044, and 050. The value of the integrand is ONE in Card ONE051, and as before SUBROUTINE STPWA controls the integration.

2.2.3 Rigid Bottom Precursor, Case $c_2 > c_4 > c_1$. The precursor for $c_2 > c_4 > c_1$ (fast shear) is based on the following equation (Britt (4-2.8))

$$P_r(t) = \frac{b(\sigma-M)}{4R_r c_4{}^4} \int_{\psi_1}^{1} \frac{(\sigma+\omega)^{1/2}A(1-\sin \pi\psi/2)\ d\psi}{(\omega-N)^{1/2}\ [\ A^2 + (B + C)^2]}$$
$$+ \frac{b(\sigma-M)}{4R_r c_4{}^4} \int_{-1}^{\psi_1} \frac{(\sigma+\omega)^{1/2}(A-B)(1-\sin \pi\psi/2)\ d\psi}{(\omega-N)^{1/2}\ [(A - B)^2 + C^2\ ]}, \qquad (2.2.13)$$

where $\psi_1 = \frac{2}{\pi} \arcsin \left[\frac{2(c_1^{-2}-c_4^{-2})^{1/2} - \sigma - M}{\sigma - M}\right]$.

(In Britt's paper the magnitude B in the second integral is denoted by B_2, a precaution unnecessary if the definition Equation (2.2.7) is used.) Equation (2.2.13) can then be written in the form used in the program

$$R_i P_r(t) = \frac{2\sqrt{2}\ b\ R_i}{\pi R_r} \int_{-\pi/2}^{\pi/2} F_x\ F_k\ dx, \qquad (2.2.14)$$

where

$$F_k = (A_x - B_x)/\left[(A_x - B_x)^2 + C_x^2\right] \text{ for } \omega^2 + c_4^{-2} - c_1^{-2} < 0 \quad (2.2.15)$$

$$F_k = A_x/\left[A_x^2 + (B_x + C_x)^2\right] \qquad \text{for } \omega^2 + c_4^{-2} - c_1^{-2} \geq 0. \quad (2.2.16)$$

The variables A_x, B_x, and C_x are defined in Equations (2.2.10), (2.2.11), and (2.2.12). In the first case the integrand is coded in Card ONE047 and the second case in Card ONE051.

2.2.4 Step Wave Response at $t = t_c$. At the peak of the bottom reflection at $t = t_c = R_r/c_1$, the step wave response $P_r(t_c)$ is calculated in the main program BOTREF. For supercritical incidence, $\theta > \theta_{cr}$, $P_r = \pm\infty$ where the sign depends on the phase shift ϕ explained in Section 2.5.1. The treatment of this case is discussed in Section 2.1.4. For subcritical incidence, $\theta < \theta_{cr}$, P_r remains finite and $P_r = K/R_r$ where K is the plane wave reflection coefficient of Section 2.5.1.

2.2.5 Non-Rigid Bottom Main Wave, Case $c_2 > c_1$. A fast non-rigid bottom ($c_2 > c_1$) has a step wave response at times $t > t_c$ given by the equation (Britt (2-2.10))

$$P_r(t) = \frac{1}{R_r}\ \frac{1-b}{1+b}$$

$$+ \frac{2b}{\pi R_r} \int_0^{\sigma} \frac{\omega(\sigma^2 - \omega^2)^{1/2}}{\left[(1-b^2)\omega^2 + \sigma^2 b^2\right]} \left\{\left[(\omega - K_m)^2 + L\right]^{-1/2} - \left[(\omega + K_m)^2 + L\right]^{-1/2}\right\} d\omega,$$

(2.2.17)

where

$$K_m = \tau_m \cos\theta \qquad (2.2.18)$$

$$L = (\tau_m^2 - c_1^{-2})\sin^2\theta. \qquad (2.2.19)$$

The subscript m has been kept to distinguish it from the reflection coefficient K.

In the code the integration variable is $w = c_1 \omega$, and the form of the equation is similar to that for the precursor:

$$R_i P_r(t) = \frac{(1-b)R_i}{(1+b)R_r} + \frac{2bR_i}{\pi R_r} \int_0^{c_1\sigma} \frac{F_x \, w \, dw}{w^2 + b^2(c_1^3\sigma^2 - w^2)}, \qquad (2.2.20)$$

where F_x is now

$$F_x = \left[\frac{c_1^2\sigma^2 - w^2}{c_1^2 L + (w - c_1 K_m)^2}\right]^{1/2} - \left[\frac{c_1^2\sigma^2 - w^2}{c_1^2 L + (w + c_1 K_m)^2}\right]^{1/2} \qquad (2.2.21)$$

$$= \left[\frac{\cos^2\alpha - w^2}{P(8) + (w - P(7))^2}\right]^{1/2} - \left[\frac{\cos^2\alpha - w^2}{P(8) + (w + P(7))^2}\right]^{1/2}$$

with $\cos\alpha = c_1\sigma = [1 - (c_1/c_2)^2]^{1/2}$.

The abbreviations P(7) and P(8) are listed in Cards STPB026 and 27.

The function F_x above is calculated in Card ONE032, and the integrand is ONE in Card ONE055. The factor outside the integral is evaluated in Card STPB032. The first term on the right hand side of Equation (2.2.20) is computed in Card STPB038. The integration for this and all other main wave responses is controlled by SUBROUTINE STPWB. The value of $R_i P_r(t)$ is calculated in Card STPB047.

2.2.6 Non-Rigid Bottom Main Wave, Case $c_1 > c_2$. The step wave response for a slow non-rigid bottom, one with $c_1 > c_2$, is expressed in the equation (Britt (2-3.14))

$$P_r(t) = \frac{1}{R_r}\,\frac{1-b}{1+b} - \frac{2\sqrt{2}\,b}{\pi R_r}\int_0^{\bar{\sigma}} \frac{\bar{\omega}(\bar{\sigma}^2-\bar{\omega}^2)^{1/2}}{(1-b^2)\bar{\omega}^2+\bar{\sigma}^2 b^2}\left\{\frac{[(\bar{\omega}^2+D)^2+E]^{1/2}+(\bar{\omega}^2-F)}{(\bar{\omega}^2+D)^2+E}\right\}^{1/2} d\bar{\omega} \qquad (2.2.22)$$

where $\bar{\sigma} = (c_2^{-2} - c_1^{-2})^{1/2}$, (2.2.23)

$D = \tau_m^2 \cos 2\theta + c_1^{-2}\sin^2\theta$, (2.2.24)

$E = 4(\sin^2\theta\cos^2\theta)\,\tau_m^2(\tau_m^2 - c_1^{-2})$, (2.2.25)

and $F = \tau_m^2 - c_1^{-2}\sin^2\theta$. (2.2.26)

The form used in the program is

$$R_i P_r(t) = \frac{R_i}{R_r}\,\frac{1-b}{1+b} - \frac{2\sqrt{2}\,b\,R_i}{\pi R_r}\int_0^{c_1\bar{\sigma}} \bar{F}_A\,\bar{F}_B\,dx\;, \qquad (2.2.27)$$

where $x = c_1\bar{\omega}$

$$\bar{F}_A = x(c_1^2\bar{\sigma}^2 - x^2)^{1/2}/[(1-b^2)x^2 + b^2 c_1^2\bar{\sigma}^2] \qquad (2.2.28)$$

$$\bar{F}_B = c_1^{-1}\left\{\frac{[(\bar{\omega}^2 + D)^2 + E]^{1/2} + (\bar{\omega}^2 - F)}{(\bar{\omega}^2 + D)^2 + E}\right\}^{1/2}. \qquad (2.2.29)$$

The integrand is evaluated in FUNCTION TWO Card TWO017, $\bar{F}_A$ is coded in Card TWO013, and $\bar{F}_B$ is coded in Cards TWO014 and 015. The terms corresponding to D, E, and F are denoted by P(11), P(12), and P(13) and are evaluated in Cards STPB029-31.

2.2.7 Rigid Bottom Main Wave, Case $c_2 > c_4 > c_1$. The rigid bottom main wave response for the case $c_2 > c_4 > c_1$ (fast shear) is expressed in Britt's equations (4-4.3), (4-3.14), and (4-3.15)

which are as follows:

$$P_r(t) = \frac{1}{R_r} + \Delta \tag{2.2.30}$$

$$+ \frac{b}{2\pi R_r c_4^4} \int_0^{\sigma_2} \frac{(\sigma^2 - \omega^2)^{1/2}(A-B)}{[(A-B)^2 + C^2]} \left\{ \frac{1}{[(\omega-K_m)^2+L]^{1/2}} - \frac{1}{[(\omega+K_m)^2+L]^{1/2}} \right\} d\omega$$

$$+ \frac{b}{2\pi R_r c_4^4} \int_{\sigma_2}^{\sigma} \frac{A(\sigma^2-\omega^2)^{1/2}}{[A^2+(B+C)^2]} \left\{ \frac{1}{[(\omega-K_m)^2+L]^{1/2}} - \frac{1}{[(\omega+K_m)^2+L]^{1/2}} \right\} d\omega$$

where $\sigma_2 = (|c_4^{-2} - c_1^{-2}|)^{1/2}$ and

$$\Delta = \frac{\sqrt{2}\,k}{R_r g_1} \left\{ \frac{(a^2+f)^{1/2} - a}{a^2 + f} \right\}^{1/2} \Gamma \tag{2.2.31}$$

with

$$\Gamma = \left\{ g_1 \left[\left(\frac{c_4^{-2}}{2} - k^2 \right)^2 - k^2 g_3 g_4 \right] - \frac{b g_3}{4 c_4^4} \right\} / \left\{ \frac{k}{g_1} \left[\left(\frac{c_4^{-2}}{2} - k^2 \right)^2 \right.\right.$$

$$\left. - k^2 g_3 g_4 \right] - g_1 k \left[4 \left(\frac{c_4^{-2}}{2} - k^2 \right) + 2 g_3 g_4 + k^2 \left(\frac{g_4}{g_3} + \frac{g_3}{g_4} \right) \right]$$

$$\left. + \frac{bk}{4 g_3 c_4^4} \right\} .$$

Here, c_{st} is the propagation velocity of the Stonley wave, $k = 1/c_{st}$, $g_1 = (k^2 - c_1^{-2})^{1/2}$, $g_3 = (k^2 - c_2^{-2})^{1/2}$, $g_4 = (k^2 - c_4^{-2})^{1/2}$, $a = \tau_m^2 - (k^2 - c_1^{-2}\cos^2\theta)$, and $f = 4\tau_m^2 g_1^2 \cos^2\theta$.

The Stonley wave propagation velocity c_{st} is calculated in SUBROUTINE STONL. The equation for c_{st} used in the program is described in Section 2.4.

The above equation is coded in the form

$$R_i P_r(t) = \frac{R_i}{R_r} + R_i \Delta + \frac{2bR_i}{\pi R_r} \int_0^{c_1 \sigma} F_x F_k \, dw . \qquad (2.2.32)$$

F_x and F_k have been defined in Equations (2.2.21), (2.2.15), and (2.2.16).

The first two terms of Equation (2.2.32) are calculated in Cards STPB056-71 for all solid bottom main waves, and the result is stored in the variable TERM1. The integrand is determined in FUNCTION ONE in Cards ONE047 and 051 in the same way as for the precursor. However, the function F_x and the factor in front of the integral are here calculated in Cards ONE032 and STPB032 as they were for a fast fluid bottom main wave.

2.2.8 Rigid Bottom Main Wave, Case $c_2 > c_1 > c_4$. The main wave response for the rigid bottom case $c_2 > c_1 > c_4$ (slow shear) is given by the following equation (Britt (4-3.13))

$$P_r(t) = \frac{1}{R_r} + \Delta$$

$$+ \frac{b}{2\pi R_r c_4{}^4} \int_0^{\sigma} \frac{A(\sigma^2 - \omega^2)^{1/2}}{A^2 + (B+C)^2} \left\{ \frac{1}{\left[(\omega - K_m)^2 + L\right]^{1/2}} - \frac{1}{\left[(\omega + K_m)^2 + L\right]^{1/2}} \right\} d\omega$$

$$- \frac{\sqrt{2}\, b}{2\pi R_r c_4{}^4} \int_0^{\sigma_2} \frac{(\bar{\omega}^2 + \sigma^2)^{1/2} \bar{B}}{(\bar{A} + \bar{C})^2 + \bar{B}^2} \left\{ \frac{\left[(\bar{\omega}^2 + D)^2 + E\right]^{1/2} + (\bar{\omega}^2 - F)}{(\bar{\omega}^2 + D)^2 + E} \right\}^{1/2} d\bar{\omega}$$

$$(2.2.33)$$

where $$\bar{A} = \bar{\omega} \left[c_4^{-2}/2 - c_1^{-2} - \bar{\omega}^2 \right]^2 , \qquad (2.2.34)$$

$$\bar{B} = \bar{\omega}\,(c_1^{-2} + \bar{\omega}^2)(\sigma^2 + \bar{\omega}^2)^{1/2}\,(\sigma_2^{\,2} - \bar{\omega}^2)^{1/2}, \tag{2.2.35}$$

$$\bar{C} = \frac{b}{4c_4^{\,4}}\,(\sigma^2 + \bar{\omega}^2)^{1/2}. \tag{2.2.36}$$

The above equation is coded in the form

$$R_1P_r(t) = \frac{R_1}{R_r} + R_1\Delta + \frac{2bR_1}{\pi R_r}\left\{\int_0^{c_1\sigma} F_xF_k\,dw - \left(\frac{c_1}{c_4}\right)^4 \frac{\sqrt{2}}{4}\int_0^{c_1\sigma_2} \bar{F}_A\bar{F}_B\,dx\right\} \tag{2.2.37}$$

where $x = c_1\bar{\omega}$, F_x and F_k are defined in Equations (2.2.21), (2.2.15), and (2.2.16),

$$\bar{F}_A = \frac{(\bar{\omega}^2 + \sigma^2)^{1/2}\,\bar{B}}{c_1^{\,4}\left[(\bar{A}+\bar{C})^2 + \bar{B}^2\right]} = \frac{(x^2 + \cos^2\alpha)^{1/2}\bar{B}_x}{(\bar{A}_x + \bar{C}_x)^2 + \bar{B}_x^2}, \tag{2.2.38}$$

$$\bar{F}_B = c_1^{-1}\left\{\frac{\left[(\bar{\omega}^2 + D)^2 + E\right]^{1/2} + (\bar{\omega}^2 - F)}{(\bar{\omega}^2 + D)^2 + E}\right\}^{1/2}, \tag{2.2.39}$$

$$\cos\alpha = c_1\sigma = \left[1 - (c_1/c_2)^2\right]^{1/2},$$

$$\bar{A}_x = c_1^{\,6}\bar{A} = x\left[\,(c_1/c_4)^2/2 - 1 - x^2\,\right]^2,$$

$$\bar{B}_x = c_1^{\,6}\bar{B} = x(1 + x^2)\left\{\left[\cos^2\alpha + x^2\right]\left[(c_1/c_4)^2 - 1 - x^2\right]\right\}^{1/2},$$

$$\bar{C}_x = c_1^{\,6}\bar{C} = b(c_1/c_4)^4\,(\cos^2\alpha + x^2)^{1/2}/4.$$

The first three terms of Equation (2.2.37) are calculated using the same cards as for the fast shear case. The integrand of the second integral is computed in FUNCTION ONE1. $\bar{F}_A$ and $\bar{F}_B$ are expressed in Cards ONE1019, 20, and 21. $\bar{A}_x$, $\bar{B}_x$, and $\bar{C}_x$ are calculated in Cards ONE1015-17. The terms corresponding to D, E, and F are denoted by P(11), P(12), and P(13) and are evaluated in Cards STPB029-31. The value of the integrand is stored in the variable ONE1 in Card ONE1023. The response STPW = $R_1P_r(t)$ is then determined in Cards STPB079 and 80.

2.3 The Complex Arithmetic Method for Calculating the Step Wave Response

A second option for calculating the step wave response is provided by the complex arithmetic method. This procedure is based on the equation (Britt (5-2.12))

$$P_r(t) = \frac{2}{\pi} \int_{y_1}^{y_2} \mathrm{Re}\left\{\frac{u}{\alpha_1 \gamma} (K - K_1)\right\} dy$$

$$+ \frac{2}{\pi R_r} \cdot \mathrm{Im}\left\{ K_1 \log\left[\frac{R_r\,\omega_2 - d_r t/R_r}{f(\omega_1)}\right]\right\} \qquad (2.3.1)$$

where $u = x + iy$ and for $t < t_c = R_r/c_1$

$$x = 0$$

$$y_1 = c_2^{-1} \qquad (2.3.2)$$

$$y_2 = R_r^{-2}\left[tr - d_r(c_1^{-2}R_r^2 - t^2)^{1/2}\right].$$

For times $t > t_c$ these variables are

$$x = R_r^{-2}\, d_r(t^2 - c_1^{-2}R_r^2)^{1/2}$$

$$y_1 = 0 \qquad (2.3.3)$$

$$y_2 = R_r^{-2}tr.$$

The reflection coefficient K for a solid bottom is defined

$$K = \frac{\alpha_1\left[(2u^2 + c_4^{-2})^2 - 4u^2\alpha_2\alpha_4\right] - b\alpha_2 c_4^{-4}}{\alpha_1\left[(2u^2 + c_4^{-2})^2 - 4u^2\alpha_2\alpha_4\right] + b\alpha_2 c_4^{-4}}, \qquad (2.3.4)$$

where $\alpha_i = (c_i^{-2} + u^2)^{1/2}$ for $i = 1, 2, 4$.

For a fluid bottom $c_4 = 0$, and the equation for K reduces to

$$K = (\alpha_1 - b\alpha_2)/(\alpha_1 + b\alpha_2). \tag{2.3.5}$$

K_1 is the value of K at $u = x + iy_2$. The other variables used above are as follows:

$$\gamma = \left[u^2 r^2 + (t - d_r\alpha_1)^2\right]^{1/2} \tag{2.3.6}$$

$$\omega_1 = \left[c_1^{-2} + (x + iy_1)^2\right]^{1/2} \tag{2.3.7}$$

$$\omega_2 = \left[c_1^{-2} + (x + iy_2)^2\right]^{1/2} \tag{2.3.8}$$

$$f(\omega_1) = \left[R_r^2\omega_1^2 - 2d_r t\omega_1 + (t^2 - c_1^{-2}r^2)\right]^{1/2} + \omega_1 R_r - d_r t/R_r. \tag{2.3.9}$$

The form of Equation (2.3.1) which is coded is

$$R_i P_r(t) = \left\{A_2 + \int_{c_1 y_1}^{c_1 y_2} \mathrm{Re}\left[F\cdot(K-K_1)\right]\, dz\right\} / \left(\frac{\pi R_r}{2R_i}\right) \tag{2.3.10}$$

where $z = c_1 y$,

$$A_2 = \mathrm{Im}\Big[K_1 \log\Big\{\left[c_1\omega_2 - c_1\tau_m\cos\theta\right] / \Big[\left(c_1^2\omega_1^2 - 2c_1\tau_m\cos\theta\,(c_1\omega_1)\right.$$
$$\left. + (c_1^2\tau_m^2 - \sin^2\theta)\right)^{1/2} + c_1\omega_1 - c_1\tau_m\cos\theta\Big]\Big\}\Big], \tag{2.3.11}$$

and

$$F = \frac{c_1 u}{c_1\alpha_1(c_1\gamma/R_r)} = \frac{uR_r}{c_1\alpha_1\gamma}. \tag{2.3.12}$$

As in the Cagniard-Rosenbaum method, the response STPW = $R_i P_r(t)$ is calculated in SUBROUTINE STPWA for the precursor ($t < t_c$) and in SUBROUTINE STPWB for the **main** wave ($t > t_c$) using the Gaussian quadrature of FGI to evaluate the integral. The last factor in Equation (2.3.10) is calculated in Cards STPA039 and STPB097. The integrand and A_2 are coded in FUNCTION SEVEN, Cards SEVN035 and 045. The value of $A_2(t)$ is obtained from STPWA by a call to SEVEN with

$z = c_1 y_2$. The function $K_1 = K(x+iy_2)$ is evaluated using the same equations as for $K(u)$ in the integral, namely, RCOE in Cards SEVN022 and 029. **In FUNCTION SEVEN the variables brought over by COMMON statements are calculated in the main program, and members of the P array are determined in Cards STPA035-38 for the precursor and in Cards STPB093-96 for the main wave.**

2.4 The Stonley Wave Propagation Velocity

The Stonley wave propagation velocity c_{st} is defined as the zeroes $u = \pm i/c_{st} = \pm ik$ of the denominator of the solid bottom reflection coefficient expressed in Equation (2.3.4). Thus $u^2 = -c_{st}^{-2}$ is the solution of the equation

$$\alpha_1\left[(2u^2 + c_4^{-2})^2 - 4u^2\alpha_2\alpha_4\right] + b\alpha_2 c_4^{-4} = 0, \qquad (2.4.1)$$

where $\alpha_1 = (c_1^{-2} + u^2)^{1/2}$,

$\alpha_2 = (c_2^{-2} + u^2)^{1/2}$,

and $\alpha_4 = (c_4^{-2} + u^2)^{1/2}$.

To obtain the form of Equation (2.4.1) which is used in the program, first note that the square roots α_1, α_2, and α_4 are imaginary since c_{st} is known to be smaller than c_1, c_2, and c_4. Next replace u^2 by $-c_{st}^{-2}$, multiply through by $ic_1 c_2 c_4{}^4 c_{st}^5$, and set $y_2 = c_{st}^2$ to obtain

$$\begin{aligned}(c_1{}^2 - y_2)^{1/2}\left\{c_2(y_2 - 2c_4{}^2)^2 - 4c_4{}^3\left[(c_2{}^2 - y_2)(c_4{}^2 - y_2)\right]^{1/2}\right\}& \\ + bc_1 y_2{}^2(c_2{}^2 - y_2)^{1/2} = 0.&\end{aligned} \qquad (2.4.2)$$

This equation is solved for y_2 in SUBROUTINE STONL by iteration using the secant method. The variable y_2 is denoted by the FORTRAN symbol Y2. Then c_{st}, called CSTON in the code, is the square root of y_2.

2.5 Theory of the Plane Wave Bottom Reflection

In cases where the plane wave bottom reflection is adequate for one's needs or when one wishes to compare these results with the spherical wave reflection, the plane wave option of the BOTREF program can be used. The reflection geometry, incident and critical angles, and the incident pulses are the same as for the spherical wave in Section 2.1; and, unless otherwise noted, the notation is the same.

2.5.1 The Plane Wave Reflection Coefficient and Phase Shift. The plane wave reflection coefficient K and phase shift ϕ for a non-rigid bottom are calculated from the following equations. For subcritical angles of incidence K and ϕ are

$$K = (A_T - 1)/(A_T + 1) \tag{2.5.1}$$

and $\phi = 0$

where $$A_T = \cos\theta/\left[b(\sin^2\theta_{cr} - \sin^2\theta)^{1/2}\right]. \tag{2.5.2}$$

At the critical angle θ_{cr} these expressions reduce to $K = 1$ and $\phi = 0$. At supercritical incidence we have

$$|K| = 1$$

and $$\phi = 2\arctan\left[b(\sin^2\theta - \sin^2\theta_{cr})^{1/2}/\cos\theta\right]. \tag{2.5.3}$$

The above equations are coded in the main program Cards BOTR260-274, 307. The FORTRAN variables CR and E2 denote K and ϕ. If K is complex, then CR = $|K|$.

For a rigid bottom K and ϕ are determined from the equations below. At subcritical incidence, $\theta < \theta_{cr} < \theta_{crs}$, we have

$$K = (A_T + B_T - 1)/(A_T + B_T + 1)$$
$$\phi = 0 \qquad (2.5.4)$$

where

$$A_T = \cos\theta\left[1 - 2\sin^2\theta/\sin^2\theta_{crs}\right]^2/\left[b(\sin^2\theta_{cr} - \sin^2\theta)^{1/2}\right] \qquad (2.5.5)$$

and

$$B_T = 4\cos\theta\sin^2\theta(\sin^2\theta_{crs} - \sin^2\theta)/$$
$$\left[b\sin^4\theta_{crs}(\sin^2\theta_{crs} - \sin^2\theta)^{1/2}\right]. \qquad (2.5.6)$$

At the critical angle $\theta = \theta_{cr}$ the equations simplify to K = 1 and $\phi = 0$. For an incident angle in the range $\theta_{cr} < \theta < \theta_{crs}$ the reflection coefficient is complex. Its modulus is

$$|K| = \left\{\left[A_{TA}^2 + (B_T - 1)^2\right]/\left[A_{TA}^2 + (B_T + 1)^2\right]\right\}^{1/2}, \qquad (2.5.7)$$

and the phase shift is

$$\phi = \arctan\left[(1-B_T)/A_{TA}\right] + \arctan\left[(1+B_T)/A_{TA}\right], \qquad (2.5.8)$$

where

$$A_{TA} = \cos\theta\left[1-2\sin^2\theta/\sin^2\theta_{crs}\right]^2/\left[b(\sin^2\theta - \sin^2\theta_{cr})^{1/2}\right] \qquad (2.5.9)$$

At the critical angle of the shear wave θ_{crs} the equations reduce to

$$|K| = 1$$

and $\qquad \phi = 2 \arctan(1/A_{TA})$. (2.5.10)

For angles of incidence $\theta > \theta_{crs}$ we have

$$|K| = 1$$

and $\qquad \phi = 2 \arctan[1/(A_{TA} + B_{TA})]$ (2.5.11)

where
$$B_{TA} = 4 \cos\theta \sin^2\theta(\sin^2\theta_{crs} - \sin^2\theta)/ \left[b \sin^4\theta_{crs}(\sin^2\theta - \sin^2\theta_{crs})^{1/2}\right] \qquad (2.5.12)$$

These equations for the solid bottom reflection coefficient and phase shift are coded in Cards BOTR280-307. As for the fluid bottom, K and ϕ are denoted by CR and E2; and if K is complex, CR= $|K|$.

2.5.2 <u>The Plane Wave Bottom Reflection Pressure History</u>.

The plane wave bottom reflection pressure history $p_r(t)$ is calculated from the following equations:

when $\qquad \theta \leq \theta_{cr}$,

$$p_r = 0 \qquad \text{for } t < t_c = R_r/c_1$$
$$p_r = p_F(R_r)\ K \exp[-(t-t_c)/G_r] \qquad \text{for } t \geq t_c \qquad (2.5.13)$$

when $\theta > \theta_{cr}$,

$$p_r = p_F(R_r) \frac{|K|}{\pi} \exp[-(t-t_c)/G_r]\, E_1[(t_c-t)/G_r] \sin\phi \qquad \text{for } \delta \leq t < t_c$$
$$(2.5.14)$$
$$p_r = \pm\infty \text{ with the sign of } \phi \qquad \text{for } t = t_c$$

$$p_r = p_F(R_r)|K| \exp[-(t-t_c)/G_r]\left\{\cos\phi - \frac{1}{\pi} Ei\left[(t-t_c)/G_r\right] \sin\phi\right\} \qquad \text{for } t > t_c. \quad (2.5.15)$$

Note that the plane wave theory has been modified to use $p_F(R_r)$ and $G_r = G(R_r)$ which account for non-linear changes of the shock wave peak pressure and time constant with distance. Also the arrival times of the main wave and precursor have been changed to conform to the spherical wave situation. In the strict plane wave theory

the precursor begins at $t = -\infty$, and the incident wave and the reflected peak arrive simultaneously.

The functions $E_1(x)$ and $Ei(x)$ are the exponential integrals defined for $x > 0$ as

$$E_1(x) = \int_x^\infty \frac{\exp(-y)}{y}\,dy \qquad (2.5.16)$$

$$Ei(x) = -\int_{-x}^\infty \frac{\exp(-y)}{y}\,dy = -E_1(-x)$$

$$= \int_{-\infty}^x \frac{\exp(y)}{y}\,dy\,. \qquad (2.5.17)$$

The function $E_1(x)$ is evaluated using the following approximate formula (see for example Abramowitz and Stegun (5))

$0 \leq x < 1$

$$E_1(x) \approx a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 + a_5 x^5 - \log(x) \qquad (2.5.18)$$

$a_0 = -.57721566$ $\qquad$ $a_3 = .05519968$

$a_1 = .99999193$ $\qquad$ $a_4 = -.00976004$

$a_2 = -.24991055$ $\qquad$ $a_5 = .00107857$

$x \geq 1$

$$x \exp(x)\, E_1(x) \approx \frac{x^4 + a_1 x^3 + a_2 x^2 + a_3 x + a_4}{x^4 + b_1 x^3 + b_2 x^2 + b_3 x + b_4} \qquad (2.5.19)$$

$a_1 = 8.5733287$ $\qquad$ $b_1 = 9.5733223$

$a_2 = 18.059017$ $\qquad$ $b_2 = 25.632956$

$a_3 = 8.6347609$ $\qquad$ $b_3 = 21.0996531$

$a_4 = .26777373$ $\qquad$ $b_4 = 3.9584969$

The function Ei(x) is evaluated for $x \leq .5$ using the formula (Reference (5))

$$Ei(x) \approx \gamma + \log (x) + \sum_{n=1}^{7} \frac{x^n}{nn!} \tag{2.5.20}$$

where $\gamma = .57721566...$ is Euler's constant. For $x > .5$, Ei(x) is obtained from

$$\exp(-x)Ei(x) = \exp(-x)Ei(1) + \int_1^x \frac{\exp(y-x)}{y} dy, \tag{2.5.21}$$

where Ei(1) = 1.8951178. The integral is then evaluated using the Gaussian quadrature of FUNCTION FGI.

The reflected pressure p_r = PBOT is calculated in the main program in Cards BOTR861-879. The exponential integrals E_1 and Ei are calculated in the subprograms EXE1 and EXEI, and the integrand of Equation (2.5.21) is coded in FUNCTION EXPO.

3. THE BOTTOM REFLECTION COMPUTER CODE

The **Bottom Reflection Code** has been programmed in FORTRAN IV for use on the CDC 6400 computer at NOL. The code is made up of a main program called BOTREF and the following bottom reflection related subprograms: STONL, STPWA, STPWB, ONE, ONE1, TWO, SEVEN, EXE1, EXEI, EXPO, FGI, PLOT1, and SCAL. In addition, the NOL general purpose plotting program CALCM1 must be included for the generation of a tape to be plotted on CALCOMP incremental plotters. For NOL users CALCM1 is available on the subroutine library tape. The control cards which are included in the program listing of Appendix A contain the statements necessary for using CALCM1 from the library tape. For programmers outside of NOL information on the plotting programs may be obtained from the NOL Mathematics Department (Code 330).

The basic organization of the bottom reflection code is as follows. The main program BOTREF handles all of the input and output and calculates the shock wave peak pressure and time constant and other time independent magnitudes. It performs the time incrementation of the pressure-time histories and calculates the convolution integral, impulse, and energy flux for the spherical wave bottom reflection.

The spherical wave step wave response $P_r(t)$ is obtained by calls from BOTREF to STPWA for the precursor and to STPWB for the main wave. These subroutines in turn set up the integration for $P_r(t)$ using the Gaussian quadrature in FGI. The various integrands described in Sections 2.2 and 2.3 are calculated in subprograms ONE, ONE1, TWO, and SEVEN. The Stonley wave propagation velocity

c_{st} for rigid bottoms is computed in SUBROUTINE STONL on a call from the main program.

The plane wave bottom reflection is also calculated in the main program. Calls to SUBROUTINES EXE1 and EXEI obtain the exponential integrals E_1 and Ei which are used to determine the bottom reflection in Equations (2.5.13), (2.5.14), and (2.5.15).

SUBROUTINES PLOT1 and SCAL set up the CALCOMP plots of the pressure-time history. PLOT1 calls SCAL to scale the plot, calls CALCM1 for plotting the axes and the pressure-time curves, and then calls SUBROUTINES SYMBL4 and NUMBR, which are part of the CALCM1 program, to write additional information on the plots.

The Bottom Reflection Program also has an option for calculating the peak translational velocity (PTV) induced in submerged or floating targets by the bottom reflected pulse. Either of the spherical or plane wave reflection theories may be used. The targets are approximated by an infinitely long cylinder of a specified radius, and the PTV Program described in Reference (6), is used to calculate the peak translational velocity. This program uses the additional subroutines PTV, FV, F1, XMAX, VTAB, and PTAB. The PTV is calculated by calling SUBROUTINE PTV (Cards BOTR813L and 813M).

The cards in the main program which are necessary for PTV calculations are denoted by card numbers followed by letters A, B, C, etc. If the bottom reflection program is not to be used for PTV calculations, these cards and the subroutines of the PTV Program may be omitted.

In the following paragraphs the most important FORTRAN symbols of each subprogram are described, and the locations in the program are given where each symbol is calculated.

3.1 FORTRAN Symbols of the Main Program

Program Input

The input data is read in Statements 3 and 4, Cards BOTR041, 42, and 89, and in Card BOTR101I using the format 8F10.5. These inputs are explained in comment Cards BOTR011-39, 72-87, and 101B-101G. The inputs and their units are as follows:

First Data Card, Statement 3

WCH charge weight W in pounds or KT

CWATER sound velocity c_1 of water in ft/sec

CBOT sound velocity c_2 of the bottom material in ft/sec

CSHEAR a double purpose input expressing the rigidity of the bottom. If CSHEAR > .5, it is the shear wave propagation velocity c_4 of the bottom in ft/sec. If CSHEAR ≤ .5, it is the dimensionless Poisson ratio from which the shear velocity c_4 is calculated in Card BOTR062. Values of c_4 ≤ .5 can be neglected.

RHOWAT density ρ_1 of water in gm/cm^3

RHOBOT density ρ_2 of the bottom material in gm/cm^3

PRECOE coefficient C_p of the pressure similitude equation in psi. PRECOE depends on whether W is in pounds or KT.

Z5 a control parameter. Z5 greater than zero results in a shorter print out for the spherical wave reflection. See Appendix B to compare the short and long print out.

Second Data Card, Statement 3

PREEXP exponent n_p of the pressure similitude equation

THECOE coefficient C_G of the time constant similitude equation in seconds. This variable also depends on the units of W.

THEEXP exponent n_G of the time constant similitude equation

STEPS number of points in the pressure-time history for one time constant G. STEPS = 20. is usually sufficient to obtain a smooth, detailed pressure history. In many cases, STEPS = 10. or 5.0 is adequate.

DURAT duration of pressure-time history in multiples of the time constant G. If negative, its absolute value is the duration after the arrival of the bottom reflection peak at $t = t_c$. If positive, it is the duration after the direct wave arrival. DURAT = -3.0 is generally sufficient for calculating the significant parts of the bottom reflection.

X1 CALCOMP plot scaling parameter for the Y-axis in psi per inch of graph. The X-axis is always drawn three inches above the bottom of the graph. The length of the Y-axis is nine inches. Thus the maximum pressure plotted is 6 * X1, and the minimum is -3 * X1. Pressures outside of this range are plotted at the maximum or minimum, whichever is applicable.

X2 scaling parameter for the X-axis in microseconds per inch of graph. If X2 ≤ 0., SUBROUTINE SCAL calculates an appropriate value of X2.

SLOPE slope of the bottom from charge to gauge in degrees. If the slope is not zero, the internal computing geometry is changed in Cards BOTR170-183. SLOPE must be zero if the geometry changing options of Z2 and THOVAL are used.

<u>Third Data Card, Statement 4</u>

BIGH water depth H at the charge in feet. BIGH is also used as a control parameter. After completion of each bottom

reflection pressure-history, the program control returns to Statement 4 to read a new set of data. If BIGH = 0., the program stops. If positive, computation continues with the new geometry. If negative, program control transfers to Statement 3 where a new set of charge, physical constants, etc., are read.

D — depth d of the charge below the water surface in feet

DGAU — depth d_g of the gauge in feet

SMALLR — horizontal range r between charge and gauge in feet

THOVAL — desired ratio between the bottom reflection incident angle θ and the critical angle θ_{cr}. The variables D and DGAU are changed in Cards BOTR137-142 to obtain this ratio. SMALLR is not changed. If THOVAL $\leq$ 0 the geometry is not changed. See Appendix C for a discussion of this option.

Z1 — parameter which selects the theory. When Z1 = 0. the spherical wave Cagniard-Rosenbaum method is used. When Z1 = 1.0, the Arons-Yennie plane wave theory is used. And for Z1 = 3.0, the complex arithmetic method is used to calculate the spherical wave bottom reflection. Cards BOTR389-403 make the theory selection and write out the appropriate headings.

Z2 — arrival time difference between the bottom reflection peak (at $t = t_c$) and the direct wave in microseconds. If Z2 $\leq$ 0., the geometry is not changed. When the geometry is changed, D and DGAU are varied to obtain the desired arrival time difference. SMALLR is not changed, and the change in D is the negative of the change in DGAU so that the incident

angle θ is also unchanged. This geometry change is performed in Cards BOTR121-127. See Appendix C for a discussion of this option.

Z3 plot control parameter. A CALCOMP plot tape is generated if Z3 = 0.

Fourth Data Card (BOTR101I), For PTV Calculation

RADIUS cylinder radius in feet. This is the draft or cross-sectional radius of the target vessel. If RADIUS ≤ 0., the PTV is not calculated.

APRINT controls printing in SUBROUTINE PTV. If APRINT ≤ 0., the translational velocities calculated in the iteration for the PTV are printed. An example of this printout is given in Table B.1 following the pressure-time history. If APRINT ≥ 0., the variables TIME1, PTV1, and PTV2 described below are printed from the main program (Card BOTR813N).

Program Output

Appendix B contains examples of the full print out and the shorter print out for the spherical wave reflection and a print out for a plane wave reflection. Most of the variables in the output are self-explanatory; others which are not so well defined are described below.

SMALLH height $h = H - d$ of the charge above the bottom

DEZERO height $d - d_g$ between the charge and gauge depths

D2 reduced height d_r/R_i from image charge to gauge

COSAL $c_1 \sigma$

COSTH $\cos \theta$

SINTH $\sin \theta$

DT increment $\Delta\bar{t}$ of the reduced time $\bar{t}$

EDT $\exp(-\Delta\bar{t}/\bar{G}_r)$

T reduced time $\bar{t}$

STPW $R_i P_r(t)$

FI/THETA $R_i F_I(t)/G_r$

PD incident pressure p_i in psi

TIME time in seconds relative to the direct wave arrival time

PBOT bottom reflected pressure p_r in psi

PS surface reflected pressure p_s in psi

P total pressure $p = p_i + p_r + p_s$ in psi. Negative pressures are cut off so that P + hydrostatic ≥ 0.

FIMP total impulse I in psi-sec calculated from the equation

$$I = \int_{t_o}^{t} p\,dt,$$ where t_o is the minimum of δ and R_i/c_1

EFLUX energy flux E_F in in-psi defined by the equation

$$E_F = \left(\int_{t_o}^{t} |p|\, p\,dt\right)/(2.3066\rho_1 c_1)$$

VMID value of STPW at $t - \Delta t$, $R_i P_r(t - \Delta t)$

PRE value of STPW at $t - 2\Delta t$

RESID $R_i \Delta$

RFIMP reduced impulse $I/W^{1/3}$

REFLUX reduced energy flux $E_F/W^{1/3}$

POSIMP impulse of the positive part of the total pressure pulse p(t)

RPOSIM reduced positive impulse, POSIMP/$W^{1/3}$

TIME1 time in seconds of the PTV, where time is taken to be zero at the beginning of the bottom reflection

PTV1 the PTV in ft/sec induced by the bottom reflection in a submerged target

PTV2 the PTV in ft/sec induced by the bottom reflection in a target at the surface

Time Independent FORTRAN Symbols

Symbol	Definition	Card Number
B	$b = \rho_1/\rho_2$	BOTR050
POISR	Poisson ratio $\bar{\sigma} = (.5c_2^2-c_4^2)/(c_2^2-c_4^2)$	59
CSHEAR	shear velocity c_4 calculated from $\bar{\sigma}$	62
CSTON	Stonley wave velocity c_{st}	69
SMALLH	h for zero slope	147
RACTU	R_i	151
PH	negative of the hydrostatic pressure at depth d_g	154
RS	reduced surface reflection arrival time	158
W13R	$W^{1/3}/R_i$	162
REDR	$R_i/W^{1/3}$	163
THETA	$\bar{G}$	164
PACT	$p_F(R_i)$	165
TACT	characteristic time R_i/c_1	166
THET	G in milliseconds	167
A	bottom slope in radians	172
D2ACTU	d_r	187
R2ACTU	R_r	188
CTWO	$\sin \theta_{cr} = c_1/c_2$	213
R2	reduced bottom reflection slant range R_r/R_i	214
THETAR	$\bar{G}_r = \bar{G}(R_r)$	215
THETR	G_r in milliseconds	216

Symbol	Definition	Card Number
PACTC	$(R_r/R_i)^{n_G-1}$	BOTR217
R1	$(R_s/R_i)^{n_G}$	218
THETSR	$\bar{G}_s$	219
SINTH	$\sin\theta$	221
COSTH	$\cos\theta$	222
D2R2	$c_1\delta/R_i$ for supercritical reflection	226
	$c_1\delta/R_i$ for subcritical reflection	228
SINAL	$\sin\theta_{cr}$	235
COSAL	$\cos\theta_{cr} = c_1\sigma$	238
SINBE	$\sin\theta_{crs}$	243
THE	incident angle θ in degrees	245
CR	plane wave reflection coefficient K	261-304
E2	phase shift ϕ in radians	260-307
EE	phase shift ϕ in degrees	308
ANGA	angle of shear wave in bottom in degrees	312,315
THONE	angle of compression wave in bottom in degrees	319,321
ALPHA	θ_{cr} in degrees	352
BETHA	θ_{crs} in degrees	358
SHD2R2	reduced arrival time of critically refracted shear wave	363-365
C2	c_1^2	446
CBOT2	c_2^2	447
CSHR2	c_4^2	448
SINTH2	$\sin^2\theta$	449
CBSH	$-4c_4^3/c_2$	450

Symbol	Definition	Card Number
C2SHR2	$2c_4^2$	BOTR451
C4CB	$c_1^4 b/c_2$	452

Spherical Wave Pressure-Time Calculations — 463-816

Symbol	Definition	Card Number
DT	increment $\Delta\bar{t}$ of reduced time increment $\Delta\bar{t}' \approx \Delta\bar{t}/8$	BOTR476,500,652 566,609
DT1	original value of $\Delta\bar{t}$	478
DTACT	$2\Delta t/3$	479,501
EDT	$\exp(-\Delta\bar{t}/\bar{G}_r)$	481,503
N	control parameter for pressure history	721,804
VMID	$R_i P_r(\bar{t} - \Delta\bar{t})$	542-662
STPW	$R_i P_r(\bar{t})$	520-690
PRE	$R_i P_r(\bar{t} - 2\Delta\bar{t})$	557-691
FI	convolution integral F_I	556-673
NP	number of subintervals to be used in the Gaussian quadrature integration for $P_r(t)$	196,552-693
V	$v(t)/t_c$ for $t \approx t_c - 2\Delta t'$ where $\Delta t'$ is approximately $\Delta t/8$	573
T1	$\bar{t}(V)$	578
T2	$\bar{t}(.75\ V)$	579
T3	$\bar{t}(.5\ V)$	580
T4	$\bar{t}(.25\ V)$	581
U	$u(t_c+2\Delta t')/t_c$ for $\Delta t' \approx \Delta t/8$	616
T2	$\bar{t}(.25\ U)$	623
T3	$\bar{t}(.5\ U)$	624
T4	$\bar{t}(.75\ U)$	625
T5	$\bar{t}(U)$	626

Symbol	Definition	Card Number
PD	incident pressure $p_i(t)$	BOTR702
PS	surface reflected pressure $p_s(t)$	704
PBOT	bottom reflected pressure $p_r(t)$	707
P	total pressure $p = p_i + p_r + p_s$. Negative values of p are cut off at p + hydrostatic $\geq$ 0.	713

Impulse and Energy Flux Calculations 717-767

Symbol	Definition	Card Number
XP	maximum of pressure p and zero	BOTR720
PMID	pressure p of even numbered time $t-\Delta t$	724
XPMID	maximum of PMID and zero	725
PPRE	pressure p at odd numbered time $t-2\Delta t$	763
XPPRE	maximum of PPRE and zero	764
PEND	pressure p(t) at odd numbered time	757
XPEND	maximum of PEND and zero	758

Variables Used in the PTV Calculation and in Plotting

Symbol	Definition	Card Number
XX	storage array for time in microseconds for CALCOMP plot. Here time is zero at the arrival of the direct wave.	BOTR800,889
YY	storage array for the total pressure p for plot	801,890
IPMAX	number of plot points stored in XX and YY arrays	807
QX	the array in which the time in seconds is stored for PTV calculations. This time is zero at the beginning of bottom reflection.	802E,813H, and 891E

Symbol	Definition	Card Number
QY	the array in which the bottom reflection pressure $p_r(t)$ is stored for PTV calculations. If $p_r(t)$ is negative, the value stored in QY is calculated so that $p_r(t)$ + hydrostatic ≥ 0	BOTR802F,813I and 891F
TIMER2	arrival time of the peak or singularity of the bottom reflection. Time in this case is measured from the beginning of the bottom reflection.	813C
XT3	signals the approach of the bottom reflection singularity. The value TIMER2 - $2\Delta t$ is used. The symbol T3 is used for this variable in SUBROUTINE PTV.	813D
XT4	The earliest time at which the translational velocity is to be calculated. The symbol T4 is used instead of XT4 in SUBROUTINE PTV.	813E
XT5	the largest value of time at which the translational velocity is to be calculated. The symbol T5 is used instead of XT5 in SUBROUTINE PTV.	813F
COSA	cosine of the angle which the bottom reflection ray makes with the water surface or a line parallel to the surface if the gauge position is below the surface	813J

Symbol	Definition	Card Number
PTS	the number of times at which the translational velocity is calculated in the initial search for the PTV. In the call to SUBROUTINE PTV the value PTS = 30. is used.	BOTR813L

Plane Wave Bottom Reflection Variables BOTR819-905

Symbol	Definition	Card Number
SW	direct wave response $p_i(t)/p_F$	BOTR852
PRFL	bottom reflection response $p_r(t)/p_F'$	857-877
TBTH	$(t - t_c)/G_r$	863
XE1	exp(-TBTH) E_1 (-TBTH)	865
XEI	exp(-TBTH) Ei(TBTH)	874

3.2 FORTRAN Symbols of SUBROUTINE STONL

Symbol	Definition
Y2	$y_2 = c_{st}^2$
FY	Equation (2.4.2) which defines y_2
CK	increment of $y_2 = y_2/1000$
CSTON	Stonley wave velocity c_{st}

3.3 FORTRAN Symbols of SUBROUTINE STPWA

Symbol	Definition	Card Number
TR	$c_1 \tau_m$	STPA013
V	$c_1 (c_1^{-2} - \tau_m^2)^{1/2}$	14
Cagniard-Rosenbaum Method, CONTR = 0.		
P(9)	0. for precursor	20
XM	$c_1 M$	21

Symbol	Definition	Card Number
P(1)	$c_1(\sigma - M)$	STPA022
P(2)	$4(c_1^{-2} - \tau_m^2)^{1/2} \sin\theta/(\sigma - M)$	23
P(5)	$c_1(\sigma + M)$	24
FACTOR	$2\sqrt{2}\ b\ R_i/\pi R_r$	25
STPW	$R_i\ P_r(t)$	27,43
Complex Arithmetic Method, CONTR = 3.0		
P(1)	$c_1 x = 0.$	35
P(2)	$c_1 \tau_m$	36
P(3)	$c_1/c_2 = c_1 y_1$	37
P(4)	$c_1 y_2$	38
FACTOR	$\pi R_r/2R_i$	39
ANS2	A_2	41

3.4 FORTRAN Symbols of SUBROUTINE STPWB

Symbol	Definition	Card Number
TR	$c_1 \tau_m$	STPB014
Cagniard-Rosenbaum Method, CONTR = 0.		
P(9)	1.0 for main wave	20
XK	$c_1 K_m$	23
XL	$c_1^2 L$	24
P(7)	XK	26
P(8)	XL	27
P(11)	$c_1{}^2 D$	29
P(12)	$c_1{}^4 E$	30
P(13)	$c_1{}^2 F$	31
FACTOR	$2bR_i/\pi R_r$	32

Symbol	Definition	Card Number
TERM1	$(R_i/R_r)(1 - b)/(1 + b)$	STPB038
SIGM	$c_1 \bar{\sigma}$	42
STPW	$R_i P_r(t)$	43,47,79,85,100
XG1	$c_1 g_1$	60
XG3	$c_1 g_3$	61
XG4	$c_1 g_4$	62
XSA	$c_1^2 a/R_i^2$	63
XSF	$c_1^4 f/R_i^4$	64
XNUM	numerator of Γ	65
XDEN	c_1^{-2} times the denominator of Γ	66-67
RESID	$R_i \Delta$	68-69
TERM1	$R_i(1/R_r + \Delta)$	71
SIG2	$c_1(c_4^{-2} - c_1^{-2})^{1/2}$	78
Complex Arithmetic Method, CONTR = 3.0		
P(1)	$c_1 x = c_1 \cos\theta(\tau_m^2 - c_1^{-2})^{1/2}$	93
P(2)	$c_1 \tau_m$	94
P(3)	$c_1 y_1 = 0$	95
P(4)	$c_1 y_2 = c_1 \tau_m \sin\theta$	96
FACTOR	$\pi R_r/2R_i$	97
ANS2	A_2	99

3.5 FORTRAN Symbols of FUNCTION ONE

Symbol	Definition	Card Number
Precursor Variables		
X	integration variable	ONE 008
W	$c_1 \omega$	20

Symbol	Definition	Card Number
XC2	$c_1^2(\sigma^2 - \omega^2)$	ONE 021,28
FX	F_x defined by Equation (2.2.4)	23
Main Reflection Variables		
W	integration variable $w = c_1\omega$	27
FX	F_x defined by Equation (2.2.21)	32
Variables for Rigid Bottom Precursors and Main Waves		
FRCS	$c_4^2(\omega^2 + \bar{c}_4^2 - \bar{c}_1^2)$	41
XA	A_x	43
XB	B_x	44
XC	C_x	50
ONE	rigid bottom integrands defined in Equations (2.2.9), (2.2.14), and (2.2.32) and the integrand of the first integral in Equation (2.2.37).	47,51
ONE	fast non-rigid bottom integrands of Equations (2.2.3) and (2.2.21)	55

3.6 FORTRAN Symbols of FUNCTION ONE1

Symbol	Definition	Card Number
X	integration variable $x = c_1\bar{\omega}$	ONE1008
XAB	$c_1^5\bar{A} = \bar{A}_x$	15
XBB	$c_1^5\bar{B} = \bar{B}_x$	16
XCB	$c_1^5\bar{C} = \bar{C}_x$	17
FAB	$\bar{F}_A$ defined by Equation (2.2.38)	19
FBB	$\bar{F}_B$ defined by Equation (2.2.39)	20,21
ONE1	integrand $\bar{F}_A\bar{F}_B$ of the second integral in Equation (2.2.37)	23

3.7 FORTRAN Symbols in FUNCTION TWO

Symbol	Definition	Card Number
X	integration variable $x = c_1 \bar{\omega}$	TWO 007
FAB	$\bar{F}_A$ defined by Equation (2.2.28)	13
FBB	$\bar{F}_B$ defined by Equation (2.2.29)	14,15
TWO	integrand in Equation (2.2.27)	17

3.8 FORTRAN Symbols in FUNCTION SEVEN

Symbol	Definition	Card Number
Z	integration variable $z = c_1 y$	SEVN007
V	$c_1 u$	14
RCOE	non-rigid bottom K defined by Equation (2.3.5)	22
	rigid bottom K defined by Equation (2.3.4)	29
F	F defined in Equation (2.3.12)	34
SEVEN	integrand of Equation (2.3.10)	35
	A_2 defined by Equation (2.3.11)	
RT5	K_1	39
U1	$x + iy_1$	40
U2	$c_1{}^2 \omega_1{}^2$	41
U3	$c_1 \omega_1$	42
XB	$-c_1 \tau_m \cos \theta$	43

3.9 FORTRAN Symbols in SUBROUTINE EXE1

Symbol	Definition	Card Number
A	array a_i in Equation (2.5.19)	EXE1008
B	array b_i in Equation (2.5.19)	9
C	array a_i in Equation (2.5.18)	10,11
X	x	12

Symbol	Definition	Card Number
ANS	$\exp(x)\ E_1(x)$ for $x \geq 1$	EXE1014,15
	$\exp(x)\ E_1(x)$ for $0 \leq x < 1$	17,18

3.10 FORTRAN Symbols in SUBROUTINE EXEI

Symbol	Definition	Card Number
Y	x	EXEI006
A	array of 1/nn! for n = 2,3,...,7 in Equation (2.5.20)	9
U	sum of the series in Equation (2.5.20)	11
ANS	$\exp(-x)Ei(x)$ using Equation (2.5.20)	12
ANS1	integral in Equation (2.5.21) evaluated using the Gaussian quadrature of FUNCTION FGI	15
ANS	$\exp(-x)Ei(x)$ using Equation (2.5.21)	16

3.11 FORTRAN Symbols in FUNCTION EXPO

Symbol	Definition
X	integration variable y in Equation (2.5.21)
P(1)	$x = (t - R_r/c_1)/G_r$
EXPO	integrand $\exp(y - x)/y$ in Equation (2.5.21)

3.12 FORTRAN Symbols in FUNCTION FGI

Symbol	Definition
A	lower limit of integration
B	upper limit of integration

Symbol	Definition
K	number of subintervals into which the integration interval (A,B) is divided. The integral in each subinterval is evaluated using a 4 point Gaussian quadrature.
F	integrand of the integral to be evaluated
P	array used to transfer parameters to the function F
FGI	value of the integral of F between A and B

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4. A. B. Arons and D. R. Yennie, "Phase Distortion of Acoustic Pulses Obliquely Reflected from a Medium of Higher Sound Velocity", Journal of the Acoustical Society of America, v. 22, 1950, pp. 231-237.

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APPENDIX A

FORTRAN IV LISTING OF THE BOTTOM REFLECTION PROGRAM BOTREF

```
BDCBOTR,T600,CM70000.52400311,047,BRITT.
ATTACH(ABC,NOLBIN)
COPYN(0,DEF,ABC)
FTN(L)
LOAD(LGO)
REQUEST,TAPE99,LO.(CALCOMP/RING)
DEF.
'      RECORD SEPARATOR =(7-8-9) PUNCH IN COLUMN 1
REWIND(ABC)
CALCM1,13,ABC
'      RECORD SEPARATOR =(7-8-9) PUNCH IN COLUMN 1
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```
      PROGRAM BOTREF(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE99)          BOTR001
C                                                                           BOTR002
C     BOTTOM REFLECTION PROGRAM (CDC 6400 COMPUTER)                         BOTR003
      DIMENSION          XX(1000),YY(1000)                                  BOTR004
      COMMON /QXY/QX(1000),QY(1000)                                        BOTR004A
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID  BOTR005
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2                        BOTR006
      ADATE = DATE(0)                                                       BOTR007
      ICASE=1                                                               BOTR008
      PI=3.1415926                                                          BOTR009
C                                                                           BOTR010
C     READ INPUT DATA (FORMAT -- 8F10.5)                                    BOTR011
C                                                                           BOTR012
C      WCH-----EXPLOSIVE CHARGE WEIGHT (LBS OR KT)                          BOTR013
C      CWATER--SOUND VELOCITY OF WATER (FT/SEC)                             BOTR014
C      CBOT----SOUND VELOCITY OF THE BOTTOM MATERIAL (FT/SEC)               BOTR015
C      CSHEAR--IF CSHEAR GT 0.5, IT IS THE SHEAR WAVE PROPAGATION           BOTR016
C              VELOCITY OF THE BOTTOM (FT/SEC).  IF CSHEAR LE 0.5, IT IS    BOTR017
C              THE DIMENSIONLESS POISSON RATIO.                             BOTR018
C      RHOWAT--DENSITY OF WATER (GM/CC)                                     BOTR019
C      RHOBOT--DENSITY OF BOTTOM MATERIAL (GM/CC)                           BOTR020
C      PRECOE--COEFFICIENT OF PRESSURE SIMILITUDE EQUATION (PSI)            BOTR021
C      Z5------CONTROL PARAMETER. Z5 GREATER THAN ZERO RESULTS IN A         BOTR022
C              SHORTER PRINT OUT.                                           BOTR023
C      PREEXP--EXPONENT OF PRESSURE SIMILITUDE EQUATION                     BOTR024
C      THECOE--COEFFICIENT OF TIME CONSTANT SIMILITUDE EQUATION (SEC)       BOTR025
C      THEEXP--EXPONENT OF TIME CONSTANT SIMILITUDE EQUATION                BOTR026
C      STEPS---NUMBER OF POINTS IN P-T CURVE FOR ONE TIME CONSTANT          BOTR027
C      DURAT---DURATION OF PRESSURE TIME HISTORY IN MULTIPLES OF THE        BOTR028
C              TIME CONSTANT. (IF NEGATIVE, ITS ABSOLUTE VALUE IS THE       BOTR029
C              DURATION AFTER THE ARRIVAL OF THE BOTTOM REFLECTION          BOTR030
C              PEAK. IF  POSITIVE, IT IS THE DURATION AFTER THE             BOTR031
C              DIRECT WAVE ARRIVAL.)                                        BOTR032
C      X1------CALCOMP PLOT SCALING PARAMETER FOR THE Y-AXIS (PSI PER       BOTR033
C              INCH OF GRAPH)                                               BOTR034
C      X2------SCALING PARAMETER FOR THE X-AXIS (MICROSECONDS PER           BOTR035
C              INCH OF GRAPH)                                               BOTR036
C      SLOPE---SLOPE OF BOTTOM FROM CHARGE TO GAUGE (DEGREES)               BOTR037
C                                                                           BOTR038
C     ADDITIONAL DATA IS READ IN STATEMENT 4 (CARD BOTR089)                 BOTR039
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```
C                                                                        BOTR040
    3 READ(5,554)WCH,CWATER,CBOT,CSHEAR,RHOWAT,RHOBOT,PRECOE,Z5          BOTR041
      READ (5,556) PREEXP,THECOE,THEEXP,STEPS,DURAT,X1,X2,SLOPE          BOTR042
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042   BOTR043
C                                                                        BOTR044
C     DURAT IN PRINT OUT IS THE DURATION AFTER THE DIRECT ARRIVAL        BOTR045
C     STORE ORIGINAL DURAT                                               BOTR046
C                                                                        BOTR047
      XDURAT=DURAT                                                       BOTR048
C                                                                        BOTR049
      B=RHOWAT/RHOBOT                                                    BOTR050
C                                                                        BOTR051
C     POISSON RATIO                                                      BOTR052
C                                                                        BOTR053
C     IF CSHEAR IS 0.5 FT/SEC OR LESS, THE POISSON RATIO POISR IS SET    BOTR054
C     EQUAL TO CSHEAR AND THE SHEAR VELOCITY IS CALCULATED.              BOTR055
C                                                                        BOTR056
      IF(CSHEAR.LE.0.) GO TO 39                                          BOTR057
      IF(CSHEAR.LE.0.5) GO TO 42                                         BOTR058
   44 POISR=(0.5*CBOT**2-CSHEAR**2)/(CBOT**2-CSHEAR**2)                  BOTR059
      GO TO 41                                                           BOTR060
   42 POISR=CSHEAR                                                       BOTR061
      CSHEAR=CBOT*SQRT((0.5-POISR)/(1.-POISR))                           BOTR062
      GO TO 41                                                           BOTR063
   39 POISR=0.5                                                          BOTR064
C                                                                        BOTR065
C                                                                        BOTR066
C     STONLEY WAVE PROPAGATION VELOCITY                                  BOTR067
C                                                                        BOTR068
   41 CALL STONL                                                         BOTR069
C                                                                        BOTR070
C                                                                        BOTR071
C     THE GEOMETRY IS NOW READ IN (FORMAT -- 8F10.5)                     BOTR072
C                                                                        BOTR073
C      BIGH----WATER DEPTH AT THE CHARGE (FT).  ALSO USED AS A           BOTR074
C              CONTROL VARIABLE. SEE CARDS BOTR094-97 BELOW              BOTR075
C      D-------DEPTH OF THE CHARGE BELOW THE WATER SURFACE (FT)          BOTR076
C      DGAU----DEPTH OF THE GAUGE (FT)                                   BOTR077
C      SMALLR--HORIZONTAL RANGE BETWEEN CHARGE AND GAUGE (FT)            BOTR078
C      THOVAL--DESIRED RATIO BETWEEN THE BOTTOM REFLECTION INCIDENT AND  BOTR079
C              CRITICAL ANGLES.  (IF THOVAL LE 0., THE INPUT GEOMETRY IS BOTR080
C              NOT CHANGED.)  SEE APPENDIX C OF NOLTR 71-110.            BOTR081
C      Z1------PARAMETER WHICH SELECTS THEORY. (SEE CARDS BOTR391-394)   BOTR082
C      Z2------ARRIVAL TIME OF THE MAIN BOTTOM REFLECTION AFTER THE      BOTR083
C              DIRECT ARRIVAL (MICROSECONDS). GEOMETRY IS UNCHANGED IF   BOTR084
C              Z2 LE 0.  SEE APPENDIX C OF NOLTR 71-110.                 BOTR085
C      Z3------PLOT CONTROL PARAMETER. A CALCOMP PLOT TAPE IS GENERATED  BOTR086
C              IF Z3 IS ZERO .                                           BOTR087
C                                                                        BOTR088
    4 READ(5,554)BIGH,D,DGAU,SMALLR,THOVAL,Z1,Z2,Z3                      BOTR089
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042   BOTR090
C     AFTER COMPLETION OF EACH CASE PROGRAM CONTROL RETURNS TO           BOTR091
C     STATEMENT 4.  DEPENDING ON BIGH, THE CALCULATIONS ARE CONTINUED AS BOTR092
C     FOLLOWS                                                            BOTR093
C     IF BIGH = 0  PROGRAM STOPS                                         BOTR094
C     IF BIGH IS POSITIVE COMPUTATION CONTINUES USING THE PRESENT INPUT  BOTR095
C     IF BIGH IS NEGATIVE PROGRAM TRANSFERS TO STATEMENT 3 WHERE         BOTR096
C     ANOTHER SET OF CHARGE, PHYSICAL CONSTANTS, ETC. ARE READ.          BOTR097
C                                                                        BOTR098
      IF(BIGH)3,1000,6                                                   BOTR099
 1000 STOP                                                               BOTR100
    6 WRITE(6,510)ADATE                                                  BOTR101
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042  BOTR101A
C     ADDITIONAL DATA IS READ IN FOR PTV CALCULATION (FORMAT -- 8F10.5) BOTR101B
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C                                                                       BOTR101C
C        RADIUS--CYLINDER RADIUS IN FEET.  THIS IS THE DRAFT OR CROSS-  BOTR101D
C                SECTIONAL RADIUS OF THE TARGET VESSEL.                 BOTR101E
C        APRINT--CONTROLS PRINTING IN SUBROUTINE PTV.  THE ITERATIONS TO BOTR101F
C                OBTAIN THE PTV ARE PRINTED OUT IF APRINT .LE. 0.       BOTR101G
C                                                                       BOTR101H
      READ(5,554) RADIUS,APRINT                                         BOTR101I
      IPTV=0                                                            BOTR101J
      A=0.                                                              BOTR101K
 1006 WRITE(6,550)ICASE                                                 BOTR102
      WRITE(6,511)BIGH                                                  BOTR103
      WRITE(6,513)D                                                     BOTR104
      WRITE(6,512)DGAU                                                  BOTR105
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042  BOTR106
C          CHANGE OF DEPTH OF EXPLOSION AND OF GAUGE FOR GIVEN ARRIVAL  BOTR107
C          TIME Z2 OF THE BOTTOM REFLECTION PEAK AFTER THE DIRECT       BOTR108
C          ARRIVAL. THE BOTTOM REFLECTION INCIDENT ANGLE AND SMALLR     BOTR109
C          ARE UNCHANGED.  SEE APPENDIX C OF NOLTR 71-110.              BOTR110
C                                                                       BOTR111
C     GEOMETRY IS UNCHANGED IF Z2 IS NEGATIVE OR ZERO.                  BOTR112
C                                                                       BOTR113
C     -D2ACTU- IS THE ORIGINAL TOTAL DISTANCE BETWEEN THE GAGE AND THE  BOTR114
C     IMAGE CHARGE. -R2ACTU- IS THE ORIGINAL TOTAL SLANT DISTANCE FROM  BOTR115
C     THE GAGE TO THE IMAGE CHARGE AND -HG- IS THE NEW VALUE OF THE     BOTR116
C     HEIGHT OF THE GAGE ABOVE THE BOTTOM.  NEW VALUES FOR -D- AND      BOTR117
C     -DGAU- ARE CALCULATED.                                            BOTR118
C                                                                       BOTR119
      IF(Z2.LE.0.) GO TO 2                                              BOTR120
    1 D2ACTU=2.*(BIGH-D)+D-DGAU                                         BOTR121
      R2ACTU=SQRT(SMALLR**2+D2ACTU**2)                                  BOTR122
      DELR=Z2*(1.E-06)*CWATER                                           BOTR123
      DR2OD2=DELR*(2.*R2ACTU-DELR)/D2ACTU**2                            BOTR124
      HG=0.5*D2ACTU*(1.-SQRT(1.-DR2OD2))                                BOTR125
      DGAU=BIGH-HG                                                      BOTR126
      D=BIGH-D2ACTU+HG                                                  BOTR127
      WRITE(6,553) Z2                                                   BOTR128
      WRITE(6,513)D                                                     BOTR129
      WRITE(6,512)DGAU                                                  BOTR130
C                                                                       BOTR131
C     CHANGE OF GEOMETRY TO OBTAIN THE DESIRED RATIO                    BOTR132
C     BETWEEN INCIDENT AND CRITICAL ANGLE=THOVAL                        BOTR133
C     GEOMETRY IS UNCHANGED IF THOVAL IS LESS THAN OR EQUAL TO ZERO.    BOTR134
C     SEE APPENDIX C OF NOLTR 71-110.                                   BOTR135
    2 IF(THOVAL.LE.0.) GO TO 5                                          BOTR136
    7 TH=THOVAL* ASIN(CWATER/CBOT)                                      BOTR137
      D2ACTU=SMALLR*COS(TH)/SIN(TH)                                     BOTR138
      D=2.*BIGH-DGAU-D2ACTU                                             BOTR139
      IF(BIGH-D) 8,9,9                                                  BOTR140
    8 D = BIGH                                                          BOTR141
      DGAU = BIGH - D2ACTU                                              BOTR142
    9 WRITE(6,537)                                                      BOTR143
      WRITE(6,512)DGAU                                                  BOTR144
      WRITE(6,513)D                                                     BOTR145
C     GEOMETRY                                                          BOTR146
    5 SMALLH=BIGH-D                                                     BOTR147
C                                                                       BOTR148
C     -RACTU- IS THE SLANT DISTANCE BETWEEN CHARGE AND GAGE.            BOTR149
C                                                                       BOTR150
      RACTU = SQRT((D-DGAU)**2+SMALLR**2)                               BOTR151
C                                                                       BOTR152
C         CALCULATE HYDROSTATIC PRESSURE -PH-                           BOTR153
      PH=-14.7*DGAU/33.0-14.7                                           BOTR154
C                                                                       BOTR155
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```
C     -RS- IS THE REDUCED ARRIVAL TIME OF ACOUSTIC SURFACE REFLECTION.
C
       RS=SQRT(SMALLR**2+(D+DGAU)**2)/RACTU
C
C     EXPONENTIAL PULSE  PEAK PRESSURE AND TIME CONSTANT CALCULATED
C
      W13R=WCH**(1./3.)/RACTU
      REDR=1./W13R
      THETA=THECOE*(W13R)**(1.+THEEXP)*CWATER
      PACT=PRECOE*(W13R)**PREEXP
      TACT=RACTU/CWATER
      THET=THETA*TACT*1000.
      IF (SLOPE .EQ. 0.) GO TO 10005
C
C     CHANGE OF GEOMETRY FOR SLOPING BOTTOM
C
      A = SLOPE/57.29578
      HG = BIGH-DGAU
      H1 = SMALLH*COS(A)
      H2 = (HG-SMALLR*TAN(A))*COS(A)
      IF((H2.LT.0.0).OR.(SMALLR*TAN(A).GT.BIGH)) WRITE(6,555)
      WRITE (6,514) SMALLR
      WRITE (6,574)
      SMALLR=SMALLR*COS(A)+(D-DGAU)*SIN(A)
      SMALLH = H1
      IF (H2 .GT. H1) D=D+H2-H1
      DGAU = D+H1-H2
      BIGH = D+H1
      WRITE (6,511) BIGH
      WRITE (6,512) DGAU
10005 DEZERO = D-DGAU
      D2ACTU=2.*SMALLH+DEZERO
      R2ACTU=SQRT(D2ACTU**2+SMALLR**2)
C
C     INITIALIZATIONS
C
 1040 FI=0.
      VMID=0.
      PRE=0.
      IP=1
      NP=4
      ZZDT=4.
      RESID=0.0
      EFLUX=0.
      FIMP=0.
      POSIMP=0.
      IPRES=-1
      PPRE=0.
      XPPRE=0.
      PMID=0.
      XPMID=0.
      PD=0.
      PS=0.
      PBOT=0.
C
C     BASIC CONSTANTS OF GROUND WAVE
C
      CTWO=CWATER/CBOT
      R2=R2ACTU/RACTU
      THETAR=THETA/R2**THEEXP
      THETB=THET/R2**THEEXP
      PACTC=R2**PREEXP/R2
      R1=RS**PREEXP
      THETSR=THETA/R1**THEEXP
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      D2=D2ACTU/RACTU                                                   BOTR220
      SINTH=SMALLR/(RACTU*R2)                                           BOTR221
      COSTH=D2/R2                                                       BOTR222
      COSRM=COSTH/R2                                                    BOTR223
      IF(CTWO.GE.SINTH) GO TO 2000                                      BOTR224
      GAM=SQRT(1.-CTWO**2)                                              BOTR225
      D2R2=R2*(CTWO*SINTH+GAM*COSTH)                                    BOTR226
      GO TO 2005                                                        BOTR227
 2000 D2R2=R2                                                           BOTR228
C                                                                       BOTR229
C     CALCULATION OF NEW DURATION IF DURAT IS READ IN NEGATIVE.         BOTR230
C     (DURAT IS EXPLAINED IN CARDS BOTR028-32.)                         BOTR231
 2005 IF(XDURAT.LT.0.) DURAT=(R2-1.)/THETA-XDURAT                       BOTR232
      TSTOP=1.+DURAT*THETA                                              BOTR233
C                                                                       BOTR234
      SINAL=CWATER/CBOT                                                 BOTR235
      SIN2AL=SINAL**2                                                   BOTR236
      IF(SIN2AL-1.)811,811,812                                          BOTR237
  811 COSAL=SQRT(1.-SIN2AL)                                             BOTR238
      GO TO 813                                                         BOTR239
  812 COSAL=-0.                                                         BOTR240
  813 SIN2TH=SINTH**2                                                   BOTR241
      IF(CSHEAR)15,15,14                                                BOTR242
   14 SINBE=CWATER/CSHEAR                                               BOTR243
      SIN2BE=SINBE**2                                                   BOTR244
   15 THE=57.2958* ASIN(SINTH)                                          BOTR245
C                                                                       BOTR246
C                                                                       BOTR247
C     CALCULATION OF PLANE WAVE REFLECTION COEFFICIENT, PHASE SHIFT,    BOTR248
C     AND ANGLE OF S-WAVE.                                              BOTR249
C                                                                       BOTR250
      IF(CSHEAR)30,30,50                                                BOTR251
C                                                                       BOTR252
C     CALCULATION FOR BOTTOM WITH NO SHEAR STRENGTH (NON-RIGID)         BOTR253
C                                                                       BOTR254
   30 IF(SIN2TH-SIN2AL)33,32,31                                         BOTR255
C                                                                       BOTR256
C     SUPERCRITICAL REFLECTION (ANGLE OF INCIDENCE GREATER THAN THE     BOTR257
C     CRITICAL ANGLE)                                                   BOTR258
C                                                                       BOTR259
   31 E=ATAN(B*SQRT(SIN2TH-SIN2AL)/COSTH)                               BOTR260
      CR=1.                                                             BOTR261
      IICA=1                                                            BOTR262
      GO TO 88                                                          BOTR263
   32 E2=0.                                                             BOTR264
      CR=1.                                                             BOTR265
      IICA=2                                                            BOTR266
      GO TO 89                                                          BOTR267
C                                                                       BOTR268
C     SUBCRITICAL REFLECTION (ANGLE OF INCIDENCE LESS THAN THE          BOTR269
C     CRITICAL ANGLE)                                                   BOTR270
C                                                                       BOTR271
   33 E2=0.                                                             BOTR272
      AT=COSTH/(SQRT(SIN2AL-SIN2TH)*B)                                  BOTR273
      CR=(AT-1.)/(AT+1.)                                                BOTR274
      IICA=3                                                            BOTR275
      GO TO 89                                                          BOTR276
C                                                                       BOTR277
C     CALCULATION FOR BOTTOM WITH SHEAR (RIGID)                         BOTR278
C                                                                       BOTR279
   50 CA=COSTH*(1.-2.*SIN2TH/SIN2BE)**2/B                               BOTR280
      CB=4.*COSTH*SIN2TH*(SIN2BE-SIN2TH)/B/SIN2BE**2                    BOTR281
      IF(SIN2TH-SIN2AL)60,32,51                                         BOTR282
   51 ATA=CA/SQRT(SIN2TH-SIN2AL)                                        BOTR283
```

```
      IF(SINTH-SINBE)52,55,57                                           BOTR284
   52 BT=CB/SQRT(SIN2BE-SIN2TH)                                         BOTR285
      CR=SQRT((ATA**2+(BT-1.)**2)/(ATA**2+(BT+1.)**2))                  BOTR286
      EA=ATAN((1.-BT)/ATA)                                              BOTR287
      EB=ATAN((1.+BT)/ATA)                                              BOTR288
      E2=EA+EB                                                          BOTR289
      IICA=4                                                            BOTR290
      GO TO 89                                                          BOTR291
   55 BTA=0.                                                            BOTR292
      GO TO 58                                                          BOTR293
C                                                                       BOTR294
   57 BTA=CB/SQRT(SIN2TH-SIN2BE)                                        BOTR295
   58 E=ATAN(1./(ATA+BTA))                                              BOTR296
      CR=1.                                                             BOTR297
      IICA=6                                                            BOTR298
      GO TO 88                                                          BOTR299
C                                                                       BOTR300
   60 E=0.                                                              BOTR301
      AT=CA/SQRT(SIN2AL-SIN2TH)                                         BOTR302
      BT=CB/SQRT(SIN2BE-SIN2TH)                                         BOTR303
      CR=(AT+BT-1.)/(AT+BT+1.)                                          BOTR304
      IICA=7                                                            BOTR305
C                                                                       BOTR306
   88 E2=2.*E                                                           BOTR307
   89 EE=57.2958*E2                                                     BOTR308
      IF(CSHEAR.LE.0.) GO TO 92                                         BOTR309
   90 IF(SINTH-SINBE)91,91,92                                           BOTR310
   91 GAMMA= ASIN(SINTH/SINBE)                                          BOTR311
      ANGA=57.2958*GAMMA                                                BOTR312
      GO TO 95                                                          BOTR313
C                                                                       BOTR314
   92 ANGA=-0.                                                          BOTR315
C                                                                       BOTR316
C     ANGLE OF P-WAVE                                                   BOTR317
   95 IF(SINTH-SINAL)293,293,294                                        BOTR318
  293 THONE=57.2958* ASIN(SINTH/SINAL)                                  BOTR319
      GO TO 295                                                         BOTR320
  294 THONE=-0.                                                         BOTR321
C                                                                       BOTR322
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042  BOTR323
  295 WRITE(6,514)SMALLR                                                BOTR324
      WRITE(6,504)WCH                                                   BOTR325
      WRITE(6,505)CWATER                                                BOTR326
      WRITE(6,506)CBOT                                                  BOTR327
      WRITE(6,546)CSHEAR                                                BOTR328
      WRITE(6,507)RHOWAT                                                BOTR329
      WRITE(6,508)RHOBOT                                                BOTR330
      WRITE(6,515)PRECOE                                                BOTR331
      WRITE(6,503)Z5                                                    BOTR332
      WRITE(6,516)PREEXP                                                BOTR333
      WRITE(6,517)THECOE                                                BOTR334
      WRITE(6,518)THEEXP                                                BOTR335
      WRITE(6,519)STEPS                                                 BOTR336
      WRITE(6,509)DURAT                                                 BOTR337
      WRITE(6,538)THOVAL                                                BOTR338
      WRITE(6,584) X1                                                   BOTR339
      WRITE(6,585) X2                                                   BOTR340
      WRITE (6,500) SLOPE                                               BOTR341
      WRITE(6,586) Z1                                                   BOTR342
      WRITE(6,587) Z2                                                   BOTR343
      WRITE(6,588)Z3                                                    BOTR344
      WRITE(6,568) RADIUS                                              BOTR344A
      WRITE(6,569) APRINT                                              BOTR344B
      WRITE(6,520)                                                      BOTR345
```

```
      WRITE(6,521)THE
      WRITE(6,573)CSTON
      WRITE(6,545)POISR
      WRITE(6,547)RS
C
      IF(1.-SINAL)17,16,16
   16 ALPHA=57.2958* ASIN(SINAL)
      WRITE(6,522)ALPHA
      GO TO 18
   17 WRITE(6,541)
   18 IF(CSHEAR)49,49,45
   45 IF(1.-SINBE)47,46,46
   46 BETHA=57.2958* ASIN(SINBE)
      WRITE(6,542)BETHA
C
C     ARRIVAL TIME OF CRITICALLY REFRACTED SHEAR WAVE
C
      IF(SINTH.LT.SINBE) SHD2R2=0.
      IF(SINTH.GE.SINBE  ) SHD2R2=(SMALLR*SINBE+O2ACTU*SQRT(1.-SIN2BE))
     1 /RACTU
      WRITE(6,579) SHD2R2
C
      GO TO 49
   47 WRITE(6,543)
   49 WRITE(6,597)THONE
      WRITE(6,592)CR
      WRITE(6,594)ANGA
      WRITE(6,593)EE
      WRITE(6,523)D2R2
      WRITE(6,533)R2
      WRITE(6,525)RACTU
      WRITE(6,502) REDR
      WRITE(6,526)TACT
      WRITE(6,527)PACT
      WRITE(6,528)THETA
      WRITE(6,539)THET
      WRITE(6,548) THETAR
      WRITE(6,549) THETR
      WRITE(6,535)
      WRITE(6,551)SMALLH,OEZERO,D2,COSAL,COSTH,SINTH
      WRITE(6,532)
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042
C
C     SELECTION OF THE THEORY
C
C     Z1=0.  ROSENBAUM METHOD
C     Z1=1.  PLANE WAVE APPROXIMATION
C     Z1=2.  NOT USED IN THE PRESENT PROGRAM
C     Z1=3.  COMPLEX ARITHMETIC METHOD
C
      Z1=ABS(Z1)
      IF(Z1-1.)800,801,802
  802 IF(Z1-3.)803,804,805
C
C     SPHERICAL WAVE CAGNIARD-ROSENBAUM THEORIES
C
  800 WRITE(6,567)
      IF(CSHEAR)820,820,821
C
C     NON-RIGID BOTTOM
  820 IF(SINAL-1.)830,831,832
C
C     FAST BOTTOM
  830 WRITE(6,560)
```

```
      GO TO 11
C
C     SLOW BOTTOM
  832 WRITE(6,561)
      GO TO 11
C
C     NO REFLECTION
  831 WRITE(6,599)
      GO TO 4
C
C     RIGID BOTTOM
  821 IF(SINBE-1.)841,841,840
C
C     FAST SHEARWAVE
  841 WRITE(6,562)
      GO TO 11
C
C     SLOW SHEARWAVE
  840 WRITE(6,563)
      GO TO 11
C
C     PLANE WAVE APPROXIMATION
  801 WRITE(6,565)
      GO TO 998
C
C     Z1 = 2. IS NOT NEEDED FOR THE PRESENT PROGRAM
C
  803 WRITE(6,599)
      GO TO 4
C
C
C     COMPLEX ARITHMETIC METHOD
C
  804 WRITE(6,566)
C
C     CONSTANTS FOR SUBROUTINE SEVEN
      C2=CWATER**2
      CBOT2=CBOT**2
      CSHR2=CSHEAR**2
      SINTH2=SINTH**2
      CBSH=-4.*CSHEAR**3/CBOT
      C2SHR2=2.*CSHEAR**2
      C4CB=C2**2/CBOT*B
      GO TO 11
C
C     Z1=4. IS NOT NEEDED FOR PRESENT PROGRAM
  805 WRITE(6,599)
      GO TO 4
C
C   ******************************************************************
C
C
C
C     SPHERICAL WAVE CAGNIARD-ROSENBAUM PRESSURE-TIME CALCULATIONS
C
C
C
C     PHASES AND TIME STEPS
C
   11 IF(D2R2-R2)10,20,20
C
C     ANGLE OF INCIDENCE GREATER THAN CRITICAL
   10 M=(R2-C2R2)*STEPS/THETA/4.
      IF((D2R2-1.0).GT.0.) M=(R2-1.0)*STEPS/THETA/4.
```

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                                                                      BOTR474
      M=4*M+5                                                         BOTR475
C     CALCULATE DT, INCREMENT OF REDUCED TIME T                       BOTR476
   12 DT=(R2-D2R2)/FLOAT(M)/2.                                        BOTR477
      IF((D2R2-1.0).GT.0.) DT=(R2-1.0)/FLOAT(M)/2.                    BOTR478
      DT1=DT                                                          BOTR479
      DTACT=2.*DT*TACT/3.                                             BOTR480
      DST=DT/3.                                                       BOTR481
      EDT=EXP(-DT/THETAR)                                             BOTR482
      WRITE(6,536)DT,EDT                                              BOTR483
      WRITE(6,532)                                                    BOTR484
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042 BOTR485
C     -Z5- IS THE PRINTOUT CONTROL PARAMETER.  IF -Z5- GREATER THAN   BOTR486
C     ZERO A SHORTER PRINTOUT RESULTS, IF -Z5- EQUALS ZERO THE NORMAL, BOTR487
C     LONGER PRINTOUT IS GENERATED.                                   BOTR488
C                                                                     BOTR489
      IF (Z5.GT. 0.0) GO TO 103                                       BOTR490
      WRITE (6,530)                                                   BOTR491
      GO TO 100                                                       BOTR492
  103 WRITE(6,501)                                                    BOTR493
      GO TO 100                                                       BOTR494
C                                                                     BOTR495
C     ANGLE OF INCIDENCE LESS THAN OR EQUAL TO CRITICAL               BOTR496
C                                                                     BOTR497
   20 MM=(R2-1.)*STEPS/THETA                                          BOTR498
      MM=2*MM+4                                                       BOTR499
C     CALCULATE DT, INCREMENT OF REDUCED TIME T                       BOTR500
      DT=(R2-1.)/FLOAT(MM)                                            BOTR501
      DTACT=2.*DT*TACT/3.                                             BOTR502
      OST=DT/3.                                                       BOTR503
      EDT=EXP(-DT/THETAR)                                             BOTR504
      WRITE(6,536)DT,EDT                                              BOTR505
      WRITE(6,532)                                                    BOTR506
      IF(Z5.GT.0.0) GO TO 104                                         BOTR507
      WRITE(6,530)                                                    BOTR508
      GO TO 700                                                       BOTR509
  104 WRITE(6,501)                                                    BOTR510
      GO TO 700                                                       BOTR511
C                                                                     BOTR512
C     ANGLE OF INCIDENT WAVE LARGER THAN CRITICAL                     BOTR513
C     R2 LARGER THAN D2R2                                             BOTR514
C                                                                     BOTR515
  100 IF(D2R2-0.9999)101,102,102                                      BOTR516
C                                                                     BOTR517
C     PRECURSOR ARRIVES BEFORE DIRECT WAVE                            BOTR518
C                                                                     BOTR519
  101 T=D2R2                                                          BOTR520
      STPW=0.                                                         BOTR521
      N=10                                                            BOTR522
      GO TO 72                                                        BOTR523
C                                                                     BOTR524
C     PRESSURE CALCULATION IF DIRECT WAVE ARRIVES BEFORE PRECURSOR    BOTR525
C                                                                     BOTR526
  102 T=1.0                                                           BOTR527
      STPW=0.                                                         BOTR528
      N=1                                                             BOTR529
      GO TO 71                                                        BOTR530
  110 N=12                                                            BOTR531
  114 T=T+2.*DT                                                       BOTR532
      IF(T.LT.D2R2) GO TO 71                                          BOTR533
  117 T=D2R2                                                          BOTR534
      WRITE(6,534)                                                    BOTR535
      N=11                                                            BOTR536
      GO TO 71                                                        BOTR537
C
```

```
C     CALCULATION OF THE PRECURSOR
C
  150 N=2
  152 T=T+DT
      CALL STPWA(T,VMID,Z1,NP)
C     EVERY FIFTH STEP RECALCULATE STPW WITH TWICE THE INTEGRATION
C     POINTS,NP, TO CHECK THE INTEGRATION ERROR.
      IF(MOD(IP,5).NE.0) GO TO 155
      IF(NP.EQ.16) GO TO 155
      NP2=2*NP
      CALL STPWA(T,VMID2,Z1,NP2)
      ERROR=ABS((VMID-VMID2)/VMID2)
      IF(ERROR.LT.0.005) GO TO 155
C     DOUBLE  NUMBER OF INTEGRATION POINTS
      NP=NP2
      VMID=VMID2
  155 T=T+DT
      CALL STPWA(T,STPW,Z1,NP)
      FI=FI*EDT**2+((PRE*EDT+4.*VMID)*EDT+STPW)*DST
      PRE=STPW
      GO TO 70
  159 IF((IPRES.LT.0).OR.(T.LT.(R2-6.1*DT))) GO TO 150
C
C     CALCULATION OF PRECURSOR NEAR SINGULARITY
C
  200 DT=DT/ZZDT
      M=(R2-T)/DT/4.
      M=4*M+5
      DT=(R2-T)/FLOAT(M)/2.
      DTACT=2.*DT*TACT/3.
      DST=DT/3.
      EDT=EXP(-DT/THETAR)
      N=9
  201 IF((IPRES.LT.0).OR.(T.LT.(R2-3.1*DT))) GO TO 152
      TR1=T/R2
      V=SQRT(1.-TR1**2)
      DSV=V/12.*R2
      TR2=SQRT(1.-(0.75*V)**2)
      TR3=SQRT(1.-(0.5*V)**2)
      TR4=SQRT(1.-(0.25*V)**2)
      T1=T
      T2=R2*TR2
      T3=R2*TR3
      T4=R2*TR4
      EDT1=EXP(-(T3-T1)/THETAR)
      EDT2=EXP(-(T3-T2)/THETAR)
      EDT3=EXP(-(R2-T3)/THETAR)
      EDT4=EXP(-(R2-T4)/THETAR)
C
  202 CALL STPWA(T2,VMID,Z1,16)
      CALL STPWA(T3,STPW,Z1,16)
      FI=FI*EDT1+(PRE*EDT1*V/TR1+3.*VMID*EDT2*V/TR2+STPW*0.5*V/TR3)*DSV
C
      PRE=STPW
      T=T3
      N=3
      GO TO 70
C
  210 CALL STPWA(T4,VMID,Z1,16)
      FI=FI*EDT3+(PRE*EDT3*0.5*V/TR3+VMID*EDT4*V/TR4)*DSV
      PRE=0.
      T=R2
      STPW=CR*(1.E+30)*SIGN(1.,EE)
      WRITE(6,540)
```

```
      N=4
      GO TO 70
C
C
C     CALCULATION OF MAIN BOTTOM REFLECTION NEAR SINGULARITY
C
  300 IF(DT.GT.(DT1/ZZDT/2.)) GO TO 301
      DT=DT1/ZZDT/2.
      DTACT=2.*DT*TACT/3.
      DST=DT/3.
      EDT=EXP(-DT/THETAR)
      NP=16
  301 T6=R2+4.*DT1
      DTR=DT/R2
      U=SQRT((1.+2.*DTR)**2-1.)
      DSU=U/12.*R2
C
      TR2=SQRT(1.+(0.25*U)**2)
      TR3=SQRT(1.+(0.50*U)**2)
      TR4=SQRT(1.+(0.75*U)**2)
      TR5=1.+2.*DTR
      T2=TR2*R2
      T3=TR3*R2
      T4=TR4*R2
      T5=TR5*R2
C
      EDT1=EXP(-(T3-R2)/THETAR)
      EDT2=EXP(-(T3-T2)/THETAR)
      EDT3=EXP(-(T5-T3)/THETAR)
      EDT4=EXP(-(T5-T4)/THETAR)
C
  302 CALL STPWB(T2,VMID,Z1,16)
      CALL STPWB(T3,STPW,Z1,16)
      FI=FI*EDT1+(VMID*U*EDT2 /TR2+STPW*0.5*U/TR3)*DSU
      PRE=STPW
      T=T3
      N=5
      GO TO 71
C
  305 CALL STPWB(T4,VMID,Z1,16)
      CALL STPWB(T5,STPW,Z1,16)
      FI=FI*EDT3+(0.5*PRE*U*EDT3/TR3+3.*VMID*U*EDT4/TR4+STPW*U/TR5)*DSU
      PRE=STPW
      T=T5
      N=6
      GO TO 71
C
  308 N=13
      DTACT=2.*TACT*DT/3.
  310 IF((IPRES.LT.0).OR.(T.LT.T6)) GO TO 410
  320 DT=DT1
      DTACT=2.*DT*TACT/3.
      DST=DT/3.
      EDT=EXP(-DT/THETAR)
C
C
C     CALCULATION OF MAIN BOTTOM REFLECTED WAVE
C
  400 N=7
  410 T=T+DT
      CALL STPWB(T,VMID,Z1,NP)
C     EVERY TENTH STEP RECALCULATE STPW WITH HALF THE INTEGRATION
C     POINTS NP.  IF ERROR IS LESS THAN .005 REDUCE NP BY HALF.
      IF(MOD(IP,10).EQ.0) GO TO 415
```

```
      IF(NP.EQ.4)  GO TO 415
      NP2=NP/2
      CALL STPWB(T,VMID2,Z1,NP2)
      ERROR=ABS((VMID-VMID2)/VMID)
      IF(ERROR.LT.0.005) NP=NP2
  415 T=T+DT
      CALL STPWB(T,STPW,Z1,NP)
      FI=FI*EDT**2+((PRE*EDT+4.*VMID)*EDT+STPW)*DST
      PRE=STPW
      GO TO 71
C
C     CALCULATION OF BOTTOM REFLECTION FOR TIMES LESS THAN OR EQUAL TO
C     THE ARRIVAL TIME OF THE PEAK IF THE ANGLE OF INCIDENCE IS LESS
C     THAN OR EQUAL TO THE CRITICAL ANGLE.  THE DIRECT WAVE ARRIVES
C     BEFORE OR TOGETHER WITH THE BOTTOM REFLECTION.
C
  700 T=1.0
      N=8
  707 STPW=0.
      GO TO 71
  706 N=14
  708 T=T+DT*2.0
      IF(T+2.0*DT.LE.R2) GO TO 71
  710 T=R2
      STPW=CR/R2
      PRE=0.
      WRITE(6,550)
      NP=8
      N=7
      GO TO 71
C
C
C     CALCULATION OF DIRECT WAVE -PD-, BOTTOM REFLECTION -PBOT-,
C     SURFACE REFLECTION -PS- AND TOTAL PRESSURE -P- .
C
   70 IF(T.LT.1.0) GO TO 72
   71 PD=PACT*EXP((1.0-T)/THETA)
      IF(T.LT.RS) GO TO 72
      PS=-PACT/R1*EXP((RS-T)/THETSR)
   72 PBOT1=PBOT
      FTHETA=FI/THETAR
      PBOT=PACT/PACTC*(STPW-FTHETA)
   73 TIME=TACT*(T-1.0)
      P= PD + PS + PBOT
C
C     TEST TO INSURE THAT THE ABSOLUTE PRESSURE (P+HYDROSTATIC) .GE. 0.
C
      P=AMAX1(P,PH)
      IF(T.GT.TSTOP) N=15
C
C
C     CALCULATION OF IMPULSE= FIMP AND ENERGY FLUX= EFLUX
C     CALCULATION OF POSITIVE IMPULSE= POSIMP
C
 6004 XP=AMAX1(P,0.)
      GO TO (6030,6007,6020,6030,6040,6050,6007,6030,6007,
     1 6030,6010,6007,6007,6007,6060),N
 6007 IF(IPRES.LT.0) GO TO 6070
      PMID=P
      XPMID=XP
      GO TO 6090
 6010 XXDT=TACT/3.*(T-TPRE)
      FIMP=3.*(P+PPRE)*XXDT /2.+FIMP
      POSIMP=3.*(XP+XPPRE)*XXDT/2.+POSIMP
```

```
      EFLUX=EFLUX+(ABS(P)*P+ABS(PPRE)*PPRE)*XXDT/2./RHOWAT/CWATER*3./    BOTR730
     1 2.3066                                                            BOTR731
C     THE CONVERSION FACTOR 2.3066 IS NECESSARY FOR EFLUX TO HAVE        BOTR732
C     UNITS IN-PSI                                                       BOTR733
      PPRE=P                                                             BOTR734
      XPPRE=XP                                                           BOTR735
      IPRES=1                                                            BOTR736
      GO TO 6092                                                         BOTR737
 6020 DTACT=2.0*DSV*TACT                                                 BOTR738
      PPRE=PPRE*V/TR1                                                    BOTR739
      XPPRE=XPPRE*V/TR1                                                  BOTR740
      PMID=P*V/2./TR3                                                    BOTR741
      XPMID=XP*V/2./TR3                                                  BOTR742
      GO TO 6090                                                         BOTR743
 6030 PEND=0.                                                            BOTR744
      XPEND=0.                                                           BOTR745
      GO TO 6072                                                         BOTR746
 6040 DTACT=2.0*DSU*TACT                                                 BOTR747
      PPRE=0.                                                            BOTR748
      XPPRE=0.                                                           BOTR749
      PMID=P*U/2./TR3                                                    BOTR750
      XPMID=XP*U/2./TR3                                                  BOTR751
      GO TO 6090                                                         BOTR752
 6050 PEND=P*U/TR5                                                       BOTR753
      XPEND=XP*U/TR5                                                     BOTR754
      GO TO 6072                                                         BOTR755
 6060 IF(IPRES.GT.0) GO TO 6010                                          BOTR756
 6070 PEND=P                                                             BOTR757
      XPEND=XP                                                           BOTR758
 6072 FIMP=FIMP+(PPRE+4.*PMID+PEND)*DTACT                                BOTR759
      POSIMP=POSIMP+(XPPRE+4.*XPMID+XPEND)*DTACT                         BOTR760
      EFLUX=EFLUX+(ABS(PPRE)*PPRE+4.*ABS(PMID)*PMID+ABS(PEND)*PEND)*     BOTR761
     1 DTACT/RHOWAT/CWATER/2.3066                                        BOTR762
      PPRE=P                                                             BOTR763
      XPPRE=XP                                                           BOTR764
 6090 IPRES=-1*IPRES                                                     BOTR765
 6092 IF(IPRES.GT.0) TPRE=T                                              BOTR766
C     WHEN D2R2.LT.1.0 THE BOTTOM REFLECTION IS NOT CALCULATED AT        BOTR767
C     THE DIRECT WAVE ARRIVAL TIME T=1.0.  IN ORDER TO PLOT THE          BOTR768
C     INSTANTANEOUS RISE OF THE DIRECT SHOCK AT T=1.0, THE BOTTOM        BOTR769
C     REFLECTION IS OBTAINED BY LINEAR INTERPOLATION.  PLOT POINTS ARE   BOTR770
C     THEN CALCULATED FOR THE TOP AND BOTTOM OF THE SHOCK FRONT.         BOTR771
      IF((IP.EQ.1).OR.(IP.GT.1000))  GO TO 7002                          BOTR772
      IF((TIME.GT.0.).AND.(XX(IP-1).LT.0.))GO TO 6095                    BOTR773
      GO TO 7002                                                         BOTR774
 6095 XX(IP)=0.                                                          BOTR775
      IF(T.NE.R2) PBOTD=PBOT1+XX(IP-1)*(PBOT-PBOT1)/(XX(IP-1)-TIME*1.E6) BOTR776
      IF(T.EQ.R2) PBOTD=PBOT1                                            BOTR777
      YY(IP)=AMAX1(PBOTD,PH)                                             BOTR778
      XX(IP+1)=0.                                                        BOTR779
      YY(IP+1)=AMAX1(PBOTD+PACT,PH)                                      BOTR780
      WRITE(6,559) YY(IP+1)                                              BOTR781
      IP=IP+2                                                            BOTR782
C     PRINT ROUTINE                                                      BOTR783
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042   BOTR784
 7002 IF (Z5.GT.0.0) GO TO 7003                                          BOTR785
      WRITE (6,551) T,STPW,FTHETA,PD,TIME,P,FIMP                         BOTR786
      WRITE(6,598)PBOT,PS,VMID,PRE,EFLUX                                 BOTR787
      GO TO 7004                                                         BOTR788
 7003 WRITE(6,551) T,PBOT,EFLUX,PD,TIME,P,FIMP                           BOTR789
      GO TO 7005                                                         BOTR790
C                                                                        BOTR791
C     REDUCED IMPULSE                                                    BOTR792
 7004 RFIMP=FIMP/W13R/RACTU                                              BOTR793
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                                                                      BOTR794
C     REDUCED POSITIVE IMPULSE                                        BOTR795
      RPOSIM=POSIMP/W13R/RACTU                                        BOTR796
C     REDUCED ENERGY FLUX                                             BOTR797
      REFLUX=EFLUX/W13R/RACTU                                         BOTR798
      WRITE(6,556) RESID,RFIMP,REFLUX,POSIMP,RPOSIM                   BOTR799
 7005 IF(IP.GT.1000) GO TO 999                                        BOTR800
      XX(IP)=TIME*1.0E6                                               BOTR801
      YY(IP)=P                                                        BOTR802
      IP=IP+1                                                         BOTR802A
C     BOTTOM REFLECTION TIME AND PRESSURE STORED IN QX AND QY FOR     BOTR802B
C     PTV CALCULATION.                                                BOTR802C
      IF(T.LT.D2R2) GO TO 7001                                        BOTR802D
      IPTV=IPTV+1                                                     BOTR802E
      QX(IPTV)=TACT*(T-D2R2)                                          BOTR802F
      QY(IPTV)=AMAX1(PBOT,PH)                                         BOTR803
C                                                                     BOTR804
 7001 GO TO (110,159,210,300,305,308,410,706,201,159,159,114,         BOTR805
     1 310,708,999),N                                                 BOTR806
C                                                                     BOTR807
  999 IPMAX=IP-1                                                      BOTR808
C                                                                     BOTR809
C     CALCOMP PLOT TAPE GENERATED IF  Z3 = 0.                         BOTR810
C                                                                     BOTR811
      IF(Z3.NE.0.) GO TO 997                                          BOTR812
      CALL PLOT1(XX,YY,IPMAX,X1,X2,ADATE,THE,WCH,CBOT,POISR,Z1)       BOTR813
  997 ICASE=ICASE+1                                                   BOTR813A
C     CALCULATION OF INPUTS FOR SUBROUTINE PTV.                       BOTR813B
      IF(RADIUS.LE.0.) GO TO 4                                        BOTR813C
 1997 TIMER2=TACT*(R2-D2R2)                                           BOTR813D
      XT3=TIMER2-2.*DT*TACT                                           BOTR813E
      XT4=0.8*TIMER2                                                  BOTR813F
      XT5=QX(IPTV)                                                    BOTR813G
      IPTV=IPTV+1                                                     BOTR813H
      QX(IPTV)=1.0E20                                                 BOTR813I
      QY(IPTV)=0.                                                     BOTR813J
      COSA=COSTH*COS(A)+SINTH*SIN(A)                                  BOTR813K
C     CALCULATION OF PEAK TRANSLATIONAL VELOCITY (PTV).               BOTR813L
      CALL PTV(TIMER2,XT3,XT4,XT5,RADIUS,30.,APRINT,COSA,RHOWAT,      BOTR813M
     1 CWATER,TIME1,PTV1,PTV2)                                        BOTR813N
      IF(APRINT.GT.0.) WRITE(6,570) TIME1,PTV1,PTV2                   BOTR814
      GO TO 4                                                         BOTR815
C                                                                     BOTR816
C    *****************************************************************BOTR817
C                                                                     BOTR818
C                                                                     BOTR819
C     PLANE WAVE APPROXIMATION USING EQUATIONS OF ARONS AND YENNIE    BOTR820
C                                                                     BOTR821
C                                                                     BOTR822
C                                                                     BOTR823
  998 IF(CSHEAR.GT.0.) GO TO 1005                                     BOTR824
      WRITE(6,590)                                                    BOTR825
      GO TO 1007                                                      BOTR826
 1005 WRITE(6,596)                                                    BOTR827
C     FORMATS ARE LISTED AT THE END OF THE PROGRAM, CARDS BOTR907-1042 BOTR828
C     SELECTION OF TIME STEP                                          BOTR829
C                                                                     BOTR830
 1007 WRITE(6,591)                                                    BOTR831
      IF(D2R2.GE.R2) GO TO 1020                                       BOTR832
C                                                                     BOTR833
C     CALCULATION OF TIME STEP FOR SUPERCRITICAL REFLECTION           BOTR834
 1010 M=(R2-D2R2)*STEPS/THETA/2.+1.0                                  BOTR835
      M=2*M-1                                                         BOTR836
      IF(M.LE.4) GO TO 1020                                           BOTR837
 1012 DT=(R2-D2R2)/FLOAT(M)
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      IF(D2R2-1.)1014,1015,1015                                        BOTR838
 1014 T=D2R2                                                           BOTR839
      GO TO 1700                                                       BOTR840
 1015 T=1.                                                             BOTR841
      GO TO 1700                                                       BOTR842
C                                                                      BOTR843
C     CALCULATION OF TIME STEP FOR SUBCRITICAL REFLECTION              BOTR844
 1020 DT=THETA/STEPS                                                   BOTR845
      T=1.                                                             BOTR846
 1700 IF(T.GE.1.0) GO TO 1731                                          BOTR847
 1730 SW=0.                                                            BOTR848
      GO TO 1732                                                       BOTR849
C                                                                      BOTR850
C     INCIDENT (DIRECT) WAVE RESPONSE                                  BOTR851
 1731 SW=EXP(-(T-1.0)/THETA)                                           BOTR852
 1732 XE1=0.                                                           BOTR853
      XEI=0.                                                           BOTR854
      IF(E2.NE.0.) GO TO 1738                                          BOTR855
 1733 IF(T.GE.R2) GO TO 1736                                           BOTR856
 1735 PRFL=0.                                                          BOTR857
      GO TO 1745                                                       BOTR858
C                                                                      BOTR859
C     PRESSURE RESPONSE FOR SUBCRITICAL REFLECTION                     BOTR860
 1736 PRFL=CR*EXP(-(T-R2)/THETAR)                                      BOTR861
      GO TO 1745                                                       BOTR862
 1738 TBTH=(T-R2)/THETAR                                               BOTR863
      IF(TBTH) 1741,1742,1743                                          BOTR864
 1741 CALL EXE1(TBTH,XE1)                                              BOTR865
C                                                                      BOTR866
C     PRESSURE RESPONSE FOR PRECURSOR OF SUPERCRITICAL REFLECTION      BOTR867
      PRFL=CR*SIN(E2)*XE1/PI                                           BOTR868
      GO TO 1745                                                       BOTR869
C                                                                      BOTR870
C     PRESSURE RESPONSE AT SINGULARITY                                 BOTR871
 1742 PRFL=(1.E+30)*SIGN(1.,EE)                                        BOTR872
      GO TO 1745                                                       BOTR873
 1743 CALL EXEI(TBTH,XEI)                                              BOTR874
C                                                                      BOTR875
C     PRESSURE RESPONSE FOR MAIN SUPERCRITICAL BOTTOM REFLECTION       BOTR876
      PRFL=CR*(EXP(-TBTH)*COS(E2)-XEI*SIN(E2)/PI)                      BOTR877
 1745 PRFL=PRFL/PACTC/R2                                               BOTR878
      PBOT=PACT*PRFL                                                   BOTR879
 1710 TIME=TACT*(T-1.)                                                 BOTR880
      PD=PACT*SW                                                       BOTR881
      IF(T.GE.RS) PS=-PACT/R1*EXP((RS-T)/THETSR)                       BOTR882
C     TOTAL PRESSURE (NEGATIVE VALUE LIMITED TO PH)                    BOTR883
      P=AMAX1(PD+PBOT+PS,PH)                                           BOTR884
C     OUTPUT ROUTINE                                                   BOTR885
      WRITE(6,551)T,PBOT,PD,PS,TIME,P                                  BOTR886
C                                                                      BOTR887
      IF(IP.GT.1000) GO TO 4000                                        BOTR888
 7100 XX(IP)=TIME*1.0E6                                                BOTR889
      YY(IP)=P                                                         BOTR890
      IP=IP+1                                                          BOTR891
C     BOTTOM REFLECTION TIME AND PRESSURE STORED IN QX AND QY FOR     BOTR891A
C     PTV CALCULATION.                                                BOTR891B
      IF(T.LT.D2R2) GO TO 7102                                        BOTR891C
      IPTV=IPTV+1                                                     BOTR891D
      QX(IPTV)=TACT*(T-D2R2)                                          BOTR891E
      QY(IPTV)=AMAX1(PBOT,PH)                                         BOTR891F
 7102 TDT=T                                                            BOTR892
      T=T+DT                                                           BOTR893
      IF(ABS(TDT-R2).LT.1.5*DT) T=TDT+0.2*DT                           BOTR894
      IF((TDT.LT.R2).AND.(T.GT.R2)) T=R2                               BOTR895
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      IF((TDT.LT.1.0).AND.(T.GT.1.0)) T=1.0                             80TR896
      IF(T.LT.TSTOP) GO TO 1700                                         80TR897
 4000 IPMAX=IP-1                                                        80TR898
C     CALCOMP PLOT TAPE IS GENERATED IF Z3 = 0.                         80TR899
      IF(Z3.NE.0.) GO TO 4001                                           80TR900
      CALL PLOT1(XX,YY,IPMAX,X1,X2,ADATE,THE,WCH,CBOT,POISR,Z1)         80TR901
 4001 ICASE=ICASE+1                                                     80TR902
      IF(RADIUS.GT.0.) GO TO 1997                                      80TR902A
      GO TO 4                                                           80TR903
C                                                                       80TR904
C     ***************************************************************** 80TR905
C                                                                       80TR906
  500 FORMAT (10X,26HSLOPE OF BOTTOM IN DEGREES,54X,6HSLOPE=,E16.8  )   80TR907
  501 FORMAT(5X,12HREDUCED TIME,23X,11HENERGY FLUX,26X,4HTIME,11X,      80TR908
     18HPRESSURE,10X,7HIMPULSE/10X,1HT,16X,4HPBOT,31X,2HPD,12X,         80TR909
     27HSECONDS,14X,3HPSI / )                                           80TR910
  502 FORMAT(10X,39HREDUCED SLANT DISTANCE (RACTU/WCH**1/3),41X,6HREDR= 80TR911
     1,1E15.8)                                                          80TR912
  503 FORMAT(10X,60HPRINT OUT CONTROL PARAMETER (Z5.GT.0. FOR SHORTER PR 80TR913
     1INT OUT),20X,3HZ5=,E16.6)                                         80TR914
  504 FORMAT(10X,40HWEIGHT OF EXPLOSIVE CHARGE IN LB (OR KT),40X,5HWCH= 80TR915
     1 E15.8 )                                                          80TR916
  505 FORMAT(10X,36HVELOCITY OF SOUND IN WATER IN FT/SEC,44X,8HCWATER= , 80TR917
     1E15.8  )                                                          80TR918
  506 FORMAT(10X,37HVELOCITY OF SOUND IN BOTTOM IN FT/SEC,43X,6HCBOT= , 80TR919
     1E15.8  )                                                          80TR920
  507 FORMAT(10X,25HDENSITY OF WATER IN GM/CC,55X,8HRHOWAT= ,E15.8  )   80TR921
  508 FORMAT(10X,26HDENSITY OF BOTTOM IN GM/CC,54X,8HRHOBOT= ,E15.8  )  80TR922
  509 FORMAT(10X,51HDURATION AFTER DIRECT ARRIVAL IN MULTIPLES OF THETA, 80TR923
     129X,7HDURAT= 1E15.8  )                                            80TR924
  510 FORMAT(1H1,52X,17HBOTTOM REFLECTION,10X,4HDATE,2X,1A10  )         80TR925
  511 FORMAT(10X,20HDEPTH OF WATER IN FT,60X,6HBIGH= 1E15.8  )          80TR926
  512 FORMAT(10X,20HDEPTH OF GAUGE IN FT,60X,6HDGAU= 1E15.8  )          80TR927
  513 FORMAT(10X,24HDEPTH OF EXPLOSION IN FT,56X,3HD= 1E15.8  )         80TR928
  514 FORMAT(10X,50HHORIZONTAL DISTANCE BETWEEN CHARGE AND GAUGE IN FT,3 80TR929
     10X,8HSMALLR= 1E15.8  )                                            80TR930
  515 FORMAT(10X,41HCOEFFICIENT OF SW PRESSURE FORMULA IN PSI,39X,      80TR931
     1 8HPRECOE= ,E15.8 )                                               80TR932
  516 FORMAT(10X,31HEXPONENT OF SW PRESSURE FORMULA,49X,8HPREEXP= ,1E15. 80TR933
     18  )                                                              80TR934
  517 FORMAT(10X,50HCOEFFICIENT OF SW TIME CONSTANT FORMULA IN SECONDS, 80TR935
     1 30X,8HTHECOE= ,E15.8 )                                           80TR936
  518 FORMAT(10X,36HEXPONENT OF SW TIME CONSTANT FORMULA,44X,8HTHEEXP= , 80TR937
     11E15.8  )                                                         80TR938
  519 FORMAT(10X,31HNUMBER OF SUBDIVISIONS OF THETA 49X,7HSTEPS= ,1E15.8 80TR939
     1  )                                                               80TR940
  520 FORMAT(1H0,47X,25HCHARACTERISTIC MAGNITUDES / )                   80TR941
  521 FORMAT(10X,33HANGLE OF INCIDENT WAVE IN DEGREES,47X,5HTHE= ,1E15.8 80TR942
     1    )                                                             80TR943
  522 FORMAT(10X,45HCRITICAL ANGLE OF COMPRESSION WAVE IN DEGREES,35X,7H 80TR944
     1ALPHA= 1E15.8 )                                                   80TR945
  523 FORMAT(10X,33HREDUCED TIME OF PRECURSOR ARRIVAL,47X,6HD2R2= ,1E15. 80TR946
     18 )                                                               80TR947
  524 FORMAT(10X,35HREDUCED TIME OF GROUND WAVE ARRIVAL,45X,4HR2= ,1E15. 80TR948
     18/ )                                                              80TR949
  525 FORMAT(10X,68HSLANT DISTANCE BETWEEN CHARGE AND GAUGE=CHARACTERIST 80TR950
     1IC LENGTH IN FT,12X,7HRACTU = ,1E15.8 )                           80TR951
  526 FORMAT(10X44HCHARACTERISTIC TIME=RACTU/CWATER IN SECONDS,36X,6HTAC 80TR952
     1T= ,1E15.8 )                                                      80TR953
  527 FORMAT(10X,58HCHARACTERISTIC PRESSURE=FREE WATER SW PEAK PRESSURE 80TR954
     1IN PSI 22X,6HPACT= ,1E15.8)                                       80TR955
  528 FORMAT(10X,38HREDUCED TIME CONSTANT OF INCIDENT WAVE,42X,7HTHETA= 80TR956
     1,1E15.8 )                                                         80TR957
  529 FORMAT(1H1)                                                       80TR958
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530 FORMAT( 5X,12HREDUCED TIME,3X,17HSTEPWAVE RESPONSE,3X,12HCONVOLUTI
   1ON-,25X,4HTIME,11X,8HPRESSURE,10X,7HIMPULSE/
   2 10X,1HT,16X,4HSTPW,11X,8HFI/THETA ,     12X,2HPO,12X,7HSECONDS
   3 ,14X,3HPSI,7X,11HENERGY FLUX/6X,10HSECOND ROW,
   4  11X,4HPROT  ,13X,2HPS,15X,4HVMID,14X,3HPRE/ 7X,9HTHIRD ROW,9X, 7H
   5RESIDUE,7X,15HREDUCED IMPULSE,3X,13HREDUCED EFLUX,6X,6HPOSIMP,
   6 24X,14HREDUCED POSIMP// )
532 FORMAT(1H0)
533 FORMAT(10X,45HREDUCED TIME OF PEAK OF BOTTOM REFLECTED WAVE,
   1 35X,4HR2= E15.8 )
534 FORMAT(50X,20HARRIVAL OF PRECURSOR / )
535 FORMAT(46X,28HCONSTANTS OF THE CALCULATION/ 9X,6HSMALLH,11X,6HDEZE
   1RO,13X,2HD2,14X,5HCOSAL,12X,5HCOSTH,12X,5HSINTH/ )
536 FORMAT(50X,2HDT,14X,3HEDT/ 40X,2E17.7/ )
537 FORMAT(24X,73HINPUT CHANGED SO THAT RATIO BETWEEN INCIDENT AND CRI
   1TICAL ANGLE IS THOVAL/ )
538 FORMAT(10X,49HDESIRED RATIO BETWEEN INCIDENT AND CRITICAL ANGLE,31
   1X,8HTHOVAL= 1E15.8   )
539 FORMAT(10X,39HACTUAL SW TIME CONSTANT IN MILLISECONDS,40X,6H THET=
   1,1E15.8 )
540 FORMAT(1H0,39X,10H********** /39X,39HARRIVAL OF GROUNDWAVE PEAK(SI
   1NGULARITY) / 40X,10H********** / )
541 FORMAT(10X,44HCRITICAL ANGLE OF COMPRESSION WAVE IMAGINARY )
542 FORMAT(10X,38HCRITICAL ANGLE OF SHEARWAVE IN DEGREES,42X,7HBETHA=
   11F7.3 )
543 FORMAT(10X,37HCRITICAL ANGLE OF SHEARWAVE IMAGINARY )
545 FORMAT(10X,13HPOISSON RATIO,67X,7HPOISR= ,1E15.8   )
546 FORMAT(10X,31HVELOCITY OF SHEARWAVE IN FT/SEC,49X,8HCSHEAR= 1E15.8
   1  )
547 FORMAT(10X,34HREDUCED TIME OF SURFACE REFLECTION,46X,4HRS= 1E15.8
   1)
548 FORMAT(10X,46HREDUCED TIME CONSTANT OF BOTTOM REFLECTED WAVE ,34X
   1 ,8HTHETAR= ,F15.8)
549 FORMAT(10X,51HBOTTOM REFLECTED WAVE TIME CONSTANT IN MILLISECONDS
   1 ,29X,7HTHETR= E15.8 / )
550 FORMAT(53X,11HRUN NUMBER ,I15/ 57X,5HINPUT// )
551 FORMAT(1X,7E17.7)
553 FORMAT(24X,59HGEOMETRY CHANGED SO THAT ARRIVAL TIME OF GROUNDWAVE
   1IS Z2 = ,E15.8/ )
554 FORMAT(8F10.5)
555 FORMAT(1H0,10H********** /5X,15H**  WARNING  ** //5X,35HSLOPE AND
   1GEOMETRY ARE INCONSISTENT /5X,52HCOMPUTATION CONTINUES BUT RESULTS
   2 MAY BE MEANINGLESS // )
556 FORMAT(18X,4E17.7,17X,E17.7/ )
558 FORMAT(39X,26HARRIVAL OF GROUNDWAVE PEAK//)
559 FORMAT(1H0,10X,27HARRIVAL OF DIRECT WAVE   P = ,E17.7 // )
560 FORMAT(50X,21HFAST NON-RIGID BOTTOM )
561 FORMAT(50X,21HSLOW NON-RIGID BOTTOM )
562 FORMAT(44X,33HRIGID BOTTOM WITH FAST SHEAR WAVE )
563 FORMAT(44X,33HRIGID BOTTOM WITH SLOW SHEAR WAVE )
C
C
565 FORMAT(48X,24HPLANE WAVE APPROXIMATION  )
566 FORMAT(45X,25HCOMPLEX ARITHMETIC METHOD )
567 FORMAT(52X,16HROSENBAUM METHOD    )
568 FORMAT(10X,21HCYLINDER RADIUS IN FT ,59X,7HRADIUS= ,E15.8 )
569 FORMAT(10X,43HPRINT CONTROL PARAMETER (FULL PRINT OUT IN ,
   1 31HSUBROUTINE PTV IF APRINT.LE.0.) ,6X,8HAPRINT= E15.8 )
570 FORMAT(1H0,18X,5HTIME1,4X,14HPTV(SUBMERGED),2X,12HPTV(SURFACE)/
   1 19X,5H(SEC),7X,8H(FT/SEC),7X,8H(FT/SEC)/11X,3E15.6)
573 FORMAT(10X,35HVELOCITY OF STONLEY WAVE IN FT/SEC   45X,7HCTSON=
   1E15.8   )
574 FORMAT(5X,10H********** ,5X,47HCALCULATION GEOMETRY CHANGED FOR SL
   1OPING BOTTOM )
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  579 FORMAT(10X,55HREDUCED ARRIVAL TIME OF CRITICALLY REFRACTED SHEAR W BOT1018
     1AVE,25X,8HSHD2R2=  E15.8)                                         BOT1019
  584 FORMAT(10X,52HSCALING PARAMETER FOR Y-AXIS (PSI PER INCH OF GRAPH) BOT1020
     1 28X,4HX1= ,E15.8  )                                              BOT1021
  585 FORMAT(10X,61HSCALING PARAMETER FOR X-AXIS (MICROSECONDS PER INCH BOT1022
     1OF GRAPH) 19X,4HX2= ,E15.8  )                                     BOT1023
  586 FORMAT(10X,29HPARAMETER THAT SELECTS THEORY,51X,4HZ1= ,E15.8  )   BOT1024
  587 FORMAT(10X,43HARRIVAL TIME OF GROUND WAVE IN MICROSECONDS 37X,4HZ2 BOT1025
     1= ,E15.8  )                                                       BOT1026
  588 FORMAT(10X,55HPLOT CONTROL PARAMETER (Z3 = 0, MEANS PLOTS ARE WANT BOT1027
     1ED) ,25X,4HZ3=  ,E15.8)                                           BOT1028
  590 FORMAT(43X,39HARONS-YENNIE APPROACH NON-RIGID BOTTOMS / )         BOT1029
  591 FORMAT( 5X,12HREDUCED TIME,3X,17HBOTTOM REFLECTION,4X,9HSHOCKWAVE, BOT1030
     1 4X,18HSURFACE REFLECTION,5X,4HTIME,8X,14HTOTAL PRESSURE/10X,     BOT1031
     2 1HT,15X,4HPBOT,14X,2HPD,15X,2HPS,12X,7HSECONDS,9X,               BOT1032
     3 7HP (PSI) / )                                                    BOT1033
  592 FORMAT(10X,22HREFLECTION COFFFICIENT,58X,4HCR= 1E15.8 )           BOT1034
  593 FORMAT(10X,30HANGLE OF PHASESHIFT IN DEGREES ,50X,4HEE= 1E15.8)   BOT1035
  594 FORMAT(10X,39HANGLE OF SHEARWAVE IN BOTTOM IN DEGREES,41X,6HANGA= BOT1036
     1 1E15.8 )                                                         BOT1037
  596 FORMAT(37X,47HARONS-YENNIE APPROACH EXTENDED TO RIGID BOTTOMS / ) BOT1038
  597 FORMAT(10X,43HANGLE OF PRESSURE WAVE IN BOTTOM IN DEGRFES,37X,8HTH BOT1039
     1EONE= ,1E15.8 )                                                   BOT1040
  598 FORMAT(18X,4E17.7,17X,E17.7)                                      BOT1041
  599 FORMAT(10X,42HINPUT INCONSISTENT. COMPUTATION SUPPRESSED/ )       BOT1042
C                                                                       BOT1043
      END                                                               BOT1044


C*****SUBROUTINE STONL****                                              STON001
C                                                                       STON002
C                                                                       STON003
C     CALCULATION OF PROPAGATION VELOCITY OF STONLEY WAVE.              STON004
C                                                                       STON005
C                                                                       STON006
      SUBROUTINE STONL                                                  STON007
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID STON008
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2                     STON009
C                                                                       STON010
      IF(CSHEAR.LE.0.) GO TO 416                                        STON011
    4 C12=CWATER**2                                                     STON012
      C32=CBOT**2                                                       STON013
      C42=CSHEAR**2                                                     STON014
C                                                                       STON015
C     ITERATION PROCESS                                                 STON016
      IF(CWATER.GT.CSHEAR) GO TO 2                                      STON017
    1 Y2=CWATER**2                                                      STON018
      GO TO 3                                                           STON019
    2 Y2=CSHEAR**2                                                      STON020
    3 CK=Y2/1000.                                                       STON021
      FY=SQRT(C12-Y2)*(CBOT*(Y2-2.*C42)**2-4.*CSHEAR*C42*SQRT((C32-Y2)*( STON022
     1C42-Y2)))+B*CWATER*Y2**2*SQRT(C32-Y2)                             STON023
      Y2=Y2-CK                                                          STON024
  400 DO 410 IR=1,999                                                   STON025
C                                                                       STON026
C     FS STORED                                                         STON027
      FS=FY                                                             STON028
C                                                                       STON029
C     STONLEY WAVE VELOCITY                                             STON030
C                                                                       STON031
      FY=SQRT(C12-Y2)*(CBOT*(Y2-2.*C42)**2-4.*CSHEAR*C42*SQRT((C32-Y2)*( STON032
     1C42-Y2)))+B*CWATER*Y2**2*SQRT(C32-Y2)                             STON033
C                                                                       STON034
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```
C
      IF(FY)412,415,408
  408 Y2=Y2-CK
  410 CONTINUE
      WRITE(6,401) CWATER,CBOT,CSHEAR,B,Y2,FS,FY
      STOP
C
C     FY IS NEGATIVE
C
C     FALSE POSITION OR SECANT METHOD ITERATION
  412 YS=Y2+CK
      DO 450 I=1,50
      YSS=Y2
      IF(ABS((YS-Y2)/YS).LT.1.0E-7) GO TO 415
  440 Y2=YS+FS*(Y2-YS)/(FS-FY)
      FS=FY
      YS=YSS
C
      FY=SQRT(C12-Y2)*(CBOT*(Y2-2.*C42)**2-4.*CSHEAR*C42*SQRT((C32-Y2)*(
     1C42-Y2)))+B*CWATER*Y2**2*SQRT(C32-Y2)
C
  450 CONTINUE
      WRITE(6,402) CWATER,CBOT,CSHEAR,B,Y2,YS,FS,FY
      STOP
C
C     RESULT
  415 CSTON=SQRT(Y2)
      RETURN
  416 CSTON=-0.
      RETURN
C
  401 FORMAT(20X, 42HFIRST ITERATION FOR CSTON DID NOT CONVERGE//
     1 30H CWATER,CBOT,CSHEAR,B,Y2,FS,FY // 1P7E16.6)
  402 FORMAT(20X, 43HSECOND ITERATION FOR CSTON DID NOT CONVERGE//
     1 33H CWATER,CBOT,CSHEAR,B,Y2,YS,FS,FY // 1P8E14.6)
C
       END


C****SUBROUTINE STPWA****
C
C
C     PRECURSOR CALCULATION USING CAGNIARD METHOD.
C
C
      SUBROUTINE STPWA(T,STPW,CONTR,K)
      DIMENSION P(30)
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2
      EXTERNAL ONE,SEVEN
      DATA AA,BB,SQ2/-1.57079633,1.57079633,1.41421356/
      TR=T/R2
      V=SQRT(1.-TR**2)
    5 IF(CONTR.EQ.3.) GO TO 100
C
C
C     CALCULATION OF THE PRECURSOR USING CAGNIARD-ROSENBAUM INTEGRALS.
C
      P(9)=0.
      XM=COSTH*TR+SINTH*V
      P(1)=COSAL-XM
      P(2)=4.*V*SINTH/P(1)
      P(5)=COSAL+XM
```

```
      FACTOR=SQ2*B/(R2*BB)                                              STPA025
C                                                                       STPA026
      STPW=FACTOR*FGI(AA,BB,K,ONE,P)                                    STPA027
C                                                                       STPA028
      RETURN                                                            STPA029
C                                                                       STPA030
C                                                                       STPA031
C                                                                       STPA032
C  CALCULATION OF THE PRECURSOR USING COMPLEX ARITHMETIC METHOD         STPA033
C                                                                       STPA034
  100 P(1)=0.                                                           STPA035
      P(2)=TR                                                           STPA036
      P(3)=CWATER/CBOT                                                  STPA037
      P(4)=SINTH*TR-COSTH*V                                             STPA038
      FACTOR=R2*BB                                                      STPA039
C                                                                       STPA040
      ANS2=SEVEN(P(4),P)                                                STPA041
C                                                                       STPA042
      STPW=(ANS2+FGI(P(3),P(4),K,SEVEN,P))/FACTOR                       STPA043
C                                                                       STPA044
      RETURN                                                            STPA045
       END                                                              STPA046


C*****SUBROUTINE STPWB****                                              STPB001
C                                                                       STPB002
C                                                                       STPB003
C     CALCULATION OF MAIN BOTTOM REFLECTION                             STPB004
C                                                                       STPB005
C                                                                       STPB006
      SUBROUTINE STPWB(T,STPW,CONTR,K)                                  STPB007
      DIMENSION P(30)                                                   STPB008
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID STPB009
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2                     STPB010
      EXTERNAL TWO,ONE1,ONE,SEVEN                                       STPB011
      DATA BB,SQ2/1.57079633,1.41421356/                                STPB012
C                                                                       STPB013
      TR=T/R2                                                           STPB014
    5 IF(CONTR.EQ.3.) GO TO 100                                         STPB015
C                                                                       STPB016
C     CALCULATION OF THE MAIN REFLECTION USING CAGNIARD-ROSENBAUM       STPB017
C     INTEGRALS.                                                        STPB018
C                                                                       STPB019
      P(9)=0.                                                           STPB020
C                                                                       STPB021
C     MAGNITUDES K AND L                                                STPB022
      XK=COSTH*TR                                                       STPB023
      XL=SINTH**2*(TR**2-1.)                                            STPB024
C                                                                       STPB025
      P(7)=XK                                                           STPB026
      P(8)=XL                                                           STPB027
C     MAGNITUDES D,E, AND F                                             STPB028
      P(11)=TR**2*(1.-2.*SINTH**2)+SINTH**2                             STPB029
      P(12)=4.*SINTH**2*COSTH**2*TR**2*(TR**2-1.)                       STPB030
      P(13)=TR**2-SINTH**2                                              STPB031
      FACTOR=B/BB/R2                                                    STPB032
      IF(CSHEAR.GT.0.) GO TO 12                                         STPB033
C                                                                       STPB034
C     NON-RIGID BOTTOMS                                                 STPB035
C                                                                       STPB036
C                                                                       STPB037
   10 TERM1=(1.-B)/(1.+B)/R2                                            STPB038
      RESID=0.                                                          STPB039
```

```
      IF(CBOT.GT.CWATER) GO TO 11
C     SLOW NON-RIGID BOTTOMS
      SIGM=SQRT((CWATER/CBOT)**2-1.)
      STPW=TERM1-SQ2*FACTOR*FGI(0.,SIGM,K,TWO,P)
      RETURN
C
C     FAST NON-RIGID BOTTOMS
   11 STPW=TERM1+FACTOR*FGI(0.,COSAL,K,ONE,P)
      RETURN
C
C
C     RIGID BOTTOMS
C
C
C     STONELEY POLE RESIDUE
C
   12 TERM=1./R2
      CWS2=(CWATER/CSHEAR)**2
      SK=CWATER/CSTON
      SK2=SK**2
      XG1=SQRT(ABS(SK2-1.))
      XG3=SQRT(ABS(SK2-(CWATER/CBOT)**2))
      XG4=SQRT(ABS(SK2-CWS2))
      XSA=R2**2*(TR**2-SK2+COSTH**2)
      XSF=(2.*R2**2*TR*COSTH*XG1)**2
      XNUM=XG1*((CWS2/2.-SK2)**2-SK2*XG3*XG4)-B*XG3*CWS2**2/4.
      XDEN=((CWS2/2.-SK2)**2-SK2*XG3*XG4)/XG1-XG1*(2.*CWS2-4.*SK2+2.*XG3
     1*XG4+SK2*(XG4/XG3+XG3/XG4))+B*CWS2**2/4./XG3
      RESID= -SQ2     *SQRT(ABS((SQRT(ABS(XSA**2+XSF))-XSA)/(XSA**2+XSF))
     1)*XNUM/XDEN/XG1
C
      TERM1=1./R2+RESID
C
      IF(CSHEAR.GT.CWATER) GO TO 50
C
C
C     SLOW SHEAR WAVE
C
   30 SIG2=SQRT(CWS2-1.)
      STPW=TERM1+FACTOR*(FGI(0.,COSAL,K,ONE,P)-CWS2**2*SQ2/4.*
     1 FGI(0.,SIG2,K,ONE1,P))
      RETURN
C
C     FAST SHEAR WAVE
C
   50 STPW=TERM1+FACTOR*FGI(0.,COSAL,K,ONE,P)
C
   99 RETURN
C
C
C
C  CALCULATION OF THE MAIN REFLECTION USING COMPLEX ARITHMETIC METHOD
C
  100 P(1)=COSTH*SQRT(TR**2-1.)
      P(2)=TR
      P(3)=0.
      P(4)=SINTH*TR
      FACTOR=R2*BB
C
      ANS2=SEVEN(P(4),P)
      STPW=(ANS2+FGI(P(3),P(4),K,SEVEN,P))/FACTOR
C
C
      RETURN
       END
```

```
C*****FUNCTION ONE****
C
C
C     INTEGRAND OF THE CAGNIARD-ROSENBAUM INTEGRAL FOR ALL FAST BOTTOMS,
C     EXCEPT FOR PART OF THE MAIN REFLECTION OF A BOTTOM WITH SLOW SHEAR
C
C
      FUNCTION ONE(X,P)
      DIMENSION P(30)
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2
C
C     P ARRAY CALCULATED IN SUBROUTINES STPWA AND STPWB
C     TEST FOR PRECURSOR PHASE
      IF(P(9).GT.0.) GO TO 2
C
C     PRECURSOR PHASE
C
      SINX=SIN(X)
      W=(SINX*P(1)+P(5))/2.
      XC2=COSAL**2-W**2
      IF(XC2.LT.0.) XC2=0.
      FX=(1.-SINX)*SQRT(((COSAL+W)*P(1))/(1.+SINX+P(2)))
      GO TO 3
C
C     MAIN REFLECTED WAVE
    2 W=X
      XC2=COSAL**2-W**2
      IF(XC2.LT.0.) XC2=0.
      RT1=SQRT(XC2/(P(8)+(W-P(7))**2))
      RT2=SQRT(XC2/(P(8)+(W+P(7))**2))
      FX=RT1-RT2
C
C     RELATIONS FOR PRECURSOR AND MAIN WAVE
C
    3 IF(CSHEAR.EQ.0.) GO TO 110
C
C     RIGID BOTTOMS
      CSW=CSHEAR/CWATER
      CSW2=CSW**2
      FRCS=CSW2*(W**2-1.)+1.
C
      XA=W*(1.-2.*CSW2*(1.-W**2))**2
      XB=4.*W*CSW2*CSW*(1.-W**2)*SQRT(XC2*ABS(FRCS))
C
      IF(FRCS.GE.0.) GO TO 22
      ONE=FX*(XA-XB)/((XA-XB)**2+B*B*XC2 )
      RETURN
C
   22 XC=B*SQRT(XC2)
      ONE=FX*XA/(XA**2+(XB+XC)**2)
      RETURN
C
C     NON-RIGID BOTTOMS
  110 ONE=FX*W/(W**2+B*B*XC2 )
      RETURN
C
       END
```

```
C*****FUNCTION ONE1****
C
C
C     INTEGRAND OF THE SECOND CAGNIARD-ROSENBAUM INTEGRAL OCCURRING FOR
C     THE MAIN REFLECTION OF A BOTTOM WITH A SLOW SHEAR WAVE.
C
C
      FUNCTION ONE1(X,P)
      DIMENSION P(30)
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2
C
    1 CWS2=(CWATER/CSHEAR)**2
      SIG22=CWS2-1.
      XAB=X*(CWS2/2.-1.-X**2)**2
      XBB=X*(1.+X**2)*SQRT((COSAL**2+X**2)*(SIG22-X**2))
      XCB=B*CWS2**2*SQRT(COSAL**2+X**2)/4.
C
      FAB=SQRT(X**2+COSAL**2)*XBB/((XAB+XCB)**2+XBB**2)
      FBB=SQRT((SQRT((X**2+P(11))**2+P(12))+X**2-P(13))/((X**2+P(11))**2
     1+P(12)))
C     P ARRAY CALCULATED IN SUBROUTINE STPWR
      ONE1=FAB*FBB
C
   99 RETURN
       END
```

```
C*****FUNCTION TWO****
C
C
C     CAGNIARD-ROSENBAUM INTEGRAND FOR SLOW NON-RIGID BOTTOMS
C
C
      FUNCTION TWO(X,P)
      DIMENSION P(30)
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2
C
      SIGM2=(CWATER/CBOT)**2-1.
      FAB=X*SQRT(SIGM2-X**2)/((1.-B**2)*X**2+SIGM2*B**2)
      FBB=SQRT((SQRT((X**2+P(11))**2+P(12))+X**2-P(13))/((X**2+P(11))**2
     1+P(12)))
C     P ARRAY CALCULATED IN SUBROUTINE STPWR
      TWO=FAB*FBB
C
      RETURN
       END
```

```
C****FUNCTION SEVEN****
C
C
C     INTEGRAND OF CAGNIARD INTEGRAL USING COMPLEX ARITHMETIC.
C
C
      FUNCTION SEVEN(Z,P)
      DIMENSION P(30)
      COMMON B,COSAL,COSTH,R2,SINBE,SINTH,CWATER,CBOT,CSHEAR,CSTON,RESID
      COMMON C2,CBOT2,CSHR2,CBSH,C2SHR2,C4CB,SINTH2
      COMPLEX F,RCOE,Y1,Y3,V,RT1,RT2,RT5,W,U1,U2,U3,U4
      COMPLEX V2,XY1,XW
```

```
C       P ARRAY CALCULATED IN SUBROUTINES STPWA AND STPWB                     SEVN013
        V=CMPLX(P(1),Z)                                                       SEVN014
        V2=V*V                                                                SEVN015
        RT1=CSQRT(1.+V2)                                                      SEVN016
        RT2=CSQRT(V2*CBOT2+C2)                                                SEVN017
        IF(CSHEAR.GT.0.) GO TO 20                                             SEVN018
C                                                                             SEVN019
C       NON-RIGID BOTTOMS                                                     SEVN020
        Y3=B/CBOT*RT2                                                         SEVN021
        RCOE=(RT1-Y3)/(RT1+Y3)                                                SEVN022
        GO TO 40                                                              SEVN023
C                                                                             SEVN024
C       RIGID BOTTOMS                                                         SEVN025
     20 XY1=C2SHR2*V2+C2                                                      SEVN026
        Y1=RT1*(XY1*XY1+CBSH*V2*RT2*CSQRT(V2*CSHR2+C2))                       SEVN027
        Y3=C4CB*RT2                                                           SEVN028
        RCOE=(Y1-Y3)/(Y1+Y3)                                                  SEVN029
     40 IF(Z.EQ.P(4)) GO TO 50                                                SEVN030
C       INTEGRAND CALCULATION                                                 SEVN031
        XW=P(2)-COSTH*RT1                                                     SEVN032
        W=V2*SINTH2+XW*XW                                                     SEVN033
        F=V/RT1/CSQRT(W)                                                      SEVN034
        SEVEN=REAL(F*(RCOE-RT5))                                              SEVN035
        RETURN                                                                SEVN036
C                                                                             SEVN037
C       CALCULATION OF ANS2                                                   SEVN038
50      RT5=RCOE                                                              SEVN039
        U1=CMPLX(P(1),P(3))                                                   SEVN040
        U2=1.+U1*U1                                                           SEVN041
        U3=CSQRT(U2)                                                          SEVN042
        XB=-P(2)*COSTH                                                        SEVN043
        U4=RT5*CLOG((RT1+XB)/(CSQRT(U2+2.*XB*U3+P(2)**2- SINTH2 )+U3+XB))     SEVN044
        SEVEN=AIMAG(U4)                                                       SEVN045
        RETURN                                                                SEVN046
         END                                                                  SEVN047


C*****SUBROUTINE EXE1****                                                     EXE1001
C                                                                             EXE1002
C                                                                             EXE1003
C       CALCULATION OF EXPONENTIAL INTEGRAL E1 TIMES EXP(-Y) , NEGATIVE Y     EXE1004
C                                                                             EXE1005
        SUBROUTINE EXE1(Y,ANS)                                                EXE1006
        DIMENSION A(4),B(4),C(6)                                              EXE1007
        DATA A/ 8.5733287,18.059017,8.6347609,0.26777373 /                    EXE1008
        DATA B/ 9.5733223,25.632956,21.0996531,3.9584969 /                    EXE1009
        DATA C/ -0.57721566,0.99999193,-0.24991055,0.05519968,-0.00976004     EXE1010
      1 ,0.00107857 /                                                         EXE1011
        X=-Y                                                                  EXE1012
        IF(X.LT.1.0) GO TO 10                                                 EXE1013
        ANS=(A(4)+X*(A(3)+X*(A(2)+X*(A(1)+X))))/(B(4)+X*(B(3)+X*(B(2)+        EXE1014
      1 X*(B(1)+X))))/X                                                       EXE1015
        RETURN                                                                EXE1016
     10 ANS=EXP(X)*(C(1)+X*(C(2)+X*(C(3)+X*(C(4)+X*(C(5)+X*C(6)))))-          EXE1017
      1 ALOG(X))                                                              EXE1018
        RETURN                                                                EXE1019
        END                                                                   EXE1020
```

```
C*****SUBROUTINE EXEI****
C
C
C     CALCULATION OF EXPONENTIAL INTEGRAL EI TIMES EXP(-Y) , POSITIVE Y
C
      SUBROUTINE EXEI(Y,ANS)
      DIMENSION P(10),A(6)
      EXTERNAL EXPO
      DATA A/ .25,.05555556,.01041667,.00166667,.00023148,.00002834 /
      IF(Y.GT.0.5) GO TO 10
      U=Y*(1.+Y*(A(1)+Y*(A(2)+Y*(A(3)+Y*(A(4)+Y*(A(5)+Y*A(6)))))))
      ANS=(0.57721566+ALOG(Y)+U)*EXP(-Y)
      RETURN
   10 P(1)=Y
      ANS1=FGI(1.,Y,4,EXPO,P)
      ANS=ANS1+1.8951178 *EXP(-Y)
      RETURN
      END


C*****FUNCTION EXPO****
C
C
C     INTEGRAND OF EXPONENTIAL INTEGRAL
C
      FUNCTION EXPO(X,P)
      DIMENSION P(10)
      EXPO=EXP(X-P(1))/X
C     P(1) IS THE ARGUMENT OF THE EXPONENTIAL INTEGRAL
      RETURN
      END


C*****FUNCTION FGI****
C
C
C     THIS SUBPROGRAM INTEGRATES THE FUNCTION F BETWEEN THE LIMITS
C     A AND B USING A FOUR-POINT GAUSSIAN QUADRATURE IN EACH OF THE
C     K SUBINTERVALS.  P IS AN ARRAY USED TO TRANSFER PARAMETERS TO THE
C     FUNCTION F.
C
      FUNCTION  FGI(A,B,K,F,P)
      DIMENSION V(4),W(2),SUM(4),P(1)
      DATA V/ -.861136311594053,-.339981043584856,
     1 .339981043584856,.861136311594053 /
      DATA W/ .347854845137454,.652145154862546 /
      SUM(1)=0.0
      SUM(2)=0.0
      SUM(3)=0.0
      SUM(4)=0.0
      H=(B-A)/FLOAT(K)
      H2=H/2.
      AA=A+H2
      DO 20 L=1,K
      DO 10 I=1,4
      X=H2*V(I)+AA
   10 SUM(I)=SUM(I)+F(X,P)
   20 AA=AA+H
      FGI=H2*(W(1)*(SUM(1)+SUM(4))+W(2)*(SUM(2)+SUM(3)))
      RETURN
      END
```

```
C*****SUBROUTINE PLOT1****
C
C
C     PLOTTING SUBROUTINE WHICH GENERATES A PLOT TAPE FOR
C     CALCOMP PLOTTER
C
      SUBROUTINE PLOT1 (XX,YY,IPMAX,X1,X2,ADATE,THE,WCH,CBOT,POISR,Z1)
      DIMENSION XX(1000),YY(1000),BCDX(2),BCDY(2),TITLE0(2),TITLE1(2),
     1TITLE2(2),TITLE4(3),TITLE5(2),TITLE6(2),TITLE7(2),TITLE8(2),
     2TITLE9(2)
      DATA BCDX/10HTIME (MICR,10HOSEC)      /,
     1BCDY/10HPRESSURE (,10HPSI)       /,
     2TITLE1/10HBOTTOM REF,10HLECTION   /,
     3TITLE2/10HCAGNIARD-R,10HOSENBAUM  /,
     4TITLE3/10HPLANE WAVE/,
     5TITLE4/10HPLANE WAVE,10H USING CON,10HV. INT.    /,
     6TITLE5/10HCOMPLEX AR,10HITHMETIC  /,
     7TITLE6/10HANGLE OF I,10HNCIDENCE  /,
     8TITLE7/10HCHARGE WEI,10HGHT (LBS) /,
     9TITLE8/10HCBOT (FT/S,10HEC)       /
      DATA TITLE9/10HPOISSON RA,10HTIO        /,
     1TITLE0(1)/10HDATE      /
      TITLE0(2)=ADATE
      YMAX=6.*X1
      YMIN=-3.*X1
      YLIN=(YMAX-YMIN)/X1
      XLMAX=90.
      XLMIN=1.
      IYYMAX=0
      DO 4 I=1,IPMAX
      IF(YY(I)-YMIN)1,1,2
    1 YY(I)=YMIN
      GO TO 4
    2 IF(YY(I)-YMAX)4,3,3
    3 YY(I)=YMAX
      IYYMAX=I
    4 CONTINUE
      XMIN=XX(1)
      XMAX=XX(IPMAX)
      CALL SCAL (X2,XMIN,XMAX,XLMIN,XLMAX,XLIN)
      IF(XMIN)5,10,10
    5 IF(XMAX)10,10,6
    6 XS=XMIN
      XN=1.
    7 IF(ABS(XS)-1.E-36)9,9,71
   71 IF(XS)8,9,100
    8 XS=XMIN+X2*XN
      XN=XN+1.
      GO TO 7
    9 XN=XN-1.5
      YN=5.16
      CALL CALCM1(IPMAX,XX,YY,0,XMIN,XMAX,YMIN,YMAX,XLIN,YLIN,TITLE,0,BC
     1DX,15,BCDY,0,FLOAT,18)
      CALL SYMBL4(XN,YN,.14,BCDY,90.,14)
      GO TO 11
   10 CALL CALCM1(IPMAX,XX,YY,0,XMIN,XMAX,YMIN,YMAX,XLIN,YLIN,TITLE,0,BC
     1DX,15,BCDY,14,FLOAT,18)
   11 IF(IYYMAX)100,12,13
   12 XS=(XMAX-XMIN)/X2-3.
      GO TO 14
   13 XS=(XX(IYYMAX)-XMIN)/X2+1.
   14 CALL SYMBL4 (XS,9.,.14,TITLE1,0.,20)
   15 IF(Z1-1.)17,18,16
   16 IF(Z1-3.)19,20,100
```

```
17 CALL SYMBL4 (XS,8.7,.14,TITLE2,0.,20)
   GO TO 21
18 CALL SYMBL4(XS,8.7,.14,TITLE3,0.,10)
   GO TO 21
19 CALL SYMBL4 (XS,8.7,.14,TITLE4,0.,30)
   GO TO 21
20 CALL SYMBL4 (XS,8.7,.14,TITLE5,0.,20)
21 CALL SYMBL4 (XS,8.4,.14,TITLE6,0.,20)
   XN=XS+.14*18.+.2
   CALL NUMBR(XN,8.4,.14,THE,0.,2)
   CALL SYMBL4 (XS,8.1,.14,TITLE7,0.,20)
   XN=XS+.14*19.+.2
   CALL NUMBR(XN,8.1,.14,WCH,0.,5)
   CALL SYMBL4 (XS,7.8,.14,TITLE8,0.,20)
   XN=XS+.14*13.+.2
   CALL NUMBR(XN,7.8,.14,CBOT,0.,2)
   CALL SYMBL4 (XS,7.5,.14,TITLE9,0.,20)
   XN=XS+.14*13.+.2
   CALL NUMBR(XN,7.5,.14,POISR,0.,5)
   CALL SYMBL4 (XS,7.2,.14,TITLE0,0.,20)
   CALL CALCM1(0,0.)
   RETURN
100 WRITE(6,22)
   CALL CALCM1(0,0.)
   STOP
22 FORMAT(1H1,10X,34HPLOTTING ERROR IN SUBROUTINE PLOT1 //)
    END
```

```
C*****SUBROUTINE SCAL****
C
C
C     SUBROUTINE FOR SCALING PLOTS
C
      SUBROUTINE SCAL (XSCALE,XMIN,XMAX,XLMIN,XLMAX,XLIN)
      DIMENSION X(6)
      SXMAX=XMAX
      SXMIN=XMIN
    1 IJ=1
    2 IF (XSCALE)3,3,6
C
C     DETERMINATION OF SCALE RANGE
C
    3 M1=ALOG10(ABS(XMIN))
      M2=ALOG10(ABS(XMAX))
      IF(IABS(IABS(M1)-IABS(M2))-1)5,4,4
    4 XM=M1
      XM=10.**XM
      GO TO 7
    5 XM=M1-1
      XM=10.**XM
      GO TO 7
    6 XM=XSCALE
C
C     SCALE FACTORS ALLOWED
C
    7 X(1)=1.*XM
      X(2)=2.*XM
      X(3)=2.5*XM
      X(4)=5.*XM
      X(5)=7.5*XM
      X(6)=10.*XM
```

```
      IF(XSCALE)8,8,24
C
C     AUTOMATIC SCALING
C
C
    8 DO 21 I=1,6
C     DETERMINATION OF SCALED MINIMUM
C
      XMIN=SXMIN
      XMAX=SXMAX
      NSCALE=XMIN/X(I)
      IF(NSCALE)11,9,12
    9 IF(XMIN)11,13,10
   10 XMIN=0.
      GO TO 13
   11 XN=NSCALE-1
      XMIN=XN*X(I)
      GO TO 13
   12 XN=NSCALE
      XMIN=XN*X(I)
C
C     DETERMINATION OF SCALED MAXIMUM
C
   13 NSCALE=XMAX/X(I)+1.
      XN=NSCALE
      XMAX=XN*X(I)
C
C     LENTH OF SCALE AXIS CALCULATED AT THIS POINT
C
      XLIN=(XMAX-XMIN)/X(I)
      IF(XLIN-XLMAX)14,18,17
   14 IF(XLIN-XLMIN)15,18,18
   15 IF(I-1)35,16,16
   16 XM=XM*1.E+01
      IJ=IJ+I
      IF(IJ-4)7,7,23
   17 IF(I-6)21,177,35
  177 XM=XM*1.E-01
      IJ=IJ+1
      IF(IJ-4)7,7,23
   18 IF(XSCALE)19,20,35
   19 IF(ABS(XSCALE)-X(I))22,20,22
   20 XSCALE=X(I)
      GO TO 39
   21 CONTINUE
   22 XSCALE=ABS(XSCALE)
      XMIN=SXMIN
      XMAX=SXMAX
      GO TO 1
   23 IF(XSCALE)38,36,35
C
C     FIXED SCALING
C
   24 DO 25 I=1,6
      IF(XSCALE-X(I))25,26,25
   25 CONTINUE
      GO TO 37
C
C     DETERMINATION OF SCALE MINIMUM
C
   26 NSCALE=XMIN/XSCALE
      IF(NSCALE)28,27,30
   27 IF(XMIN)28,31,29
```

```
   28 XN=NSCALE-1
      XMIN=XN*XSCALE
      GO TO 31
   29 XMIN=0.
      GO TO 31
   30 XN=NSCALE
      XMIN=XN*XSCALE
C
C     DETERMINATION OF SCALED MAXIMUM
C
   31 NSCALE=XMAX/XSCALE+1.
      XN=NSCALE
      XMAX=XN*XSCALE
C
C     LENGTH OF SCALE AXIS
C
      XLIN=(XMAX-XMIN)/XSCALE
      IF(XLIN-XLMAX)32,39,33
   32 IF(XLIN-XLMIN)34,39,39
   33 XSCALE=XSCALE*1.E+01
      IJ=IJ+1
      IF(IJ-4)2,2,37
   34 XSCALE=XSCALE*1.E-01
      IJ=IJ+1
      IF(IJ-4)2,2,37
   35 STOP
   36 WRITE(6,200)XMAX,XMIN,XLIN,(X(I),I=1,6)
      GO TO 35
   37 WRITE(6,201)XMAX,XMIN,XLIN,(X(I),I=1,6)
      GO TO 35
   38 WRITE(6,202)XMAX,XMIN,XLIN,(X(I),I=1,6)
      GO TO 22
  200 FORMAT(42X,36HAUTOMATIC SCALING CANNOT BE ACHIEVED/30X,5HXMAX=1E14
     1.5,2X,5HXMIN=1E14.5,2X,5HXLIN=1E14.5//51X,17HSCALE FACTORS ARE//18
     2X,6E14.5//)
  201 FORMAT(45X,32HFIXED SCALING CANNOT BE ACHIEVED/30X,5HXMAX=1E14.5,2
     1X,5HXMIN=1E14.5,2X,5HXLIN=1E14.5//51X,17HSCALE FACTORS ARE//18X,6E
     214.5//)
  202 FORMAT(9X,76HAUTOMATIC SCALING CANNOT ACHIEVE DESIRED SCALE FACTOR
     1,WILL TRY FIXED SCALING//30X,5HXMAX=1E14.5,2X,5HXMIN=1E14.5,2X,5HX
     2LIN=1E14.5//51X,17HSCALE FACTORS ARE//18X,6E14.5//)
   39 RETURN
      END
```

```
C     ***** PTV PROGRAM *****
C
      SUBROUTINE PTV(TIMER2,T3,T4,T5,RAD,PTS,OPTION,COSA,RHOW,CWAT,
     1 T,V,VS)
C
C     THIS SUBPROGRAM CONTROLS THE ITERATION FOR THE PEAK
C     TRANSLATIONAL VELOCITY, PTV.  IT IS THE ONLY SUBROUTINE OF THE
C     PTV PROGRAM WHICH IS CALLED FROM THE MAIN PROGRAM.
C
      DIMENSION QX(1000),QY(1000),IS(2)
      DIMENSION G(6)
      DIMENSION A(50),C(50)
      COMMON /QXY/QX,QY
      COMMON /QIS/IS
C
C
      IF(OPTION.GT.0.) GO TO 10
      WRITE(6,580)
      WRITE(6,600) TIMER2,T3,T4,T5,RAD,PTS,OPTION,COSA,RHOW,CWAT
      WRITE(6,590)
C
C     74.21457 IS A UNITS CONVERSION FACTOR
   10 VC=2.*74.21457/RHOW/RAD
      N=PTS
      T=T4
      DT=(T5-T)/FLOAT(N-1)
      IF(T.LE.0.) N=N-1
      IF(T.LE.0.) T=DT/2.
      IS(1)=2
      IS(2)=1
      G(2)=CWAT/RAD
      G(3)=TIMER2
      G(5)=SQRT(TIMER2-T3)
      G(6)=SQRT(TIMER2)
C     INITIAL SEARCH FOR MAXIMUM VELOCITY
      DO 40 I=1,N
      G(1)=T
      V=VC*FV(G)
      A(I)=T
      C(I)=V
      VS=2.*COSA*V
      IF(OPTION.LE.0.) WRITE(6,610) T,V,VS
      T=T+DT
   40 CONTINUE
C     ITERATION FOR PTV
C     DETERMINE THE MAXIMUM VELOCITY FROM C ARRAY
      CALL XMAX(C,N,M,M1)
      A2=A(M1)
      C2=C(M1)
      A(1)=A(M)
      C(1)=C(M)
      A(2)=A2
      C(2)=C2
      DA=DT
      T=A(1)-1.8*DA
      IF(T.LE.0.) T=DA/5.
      DT=DA/2.
      DO 45 I=3,10
      G(1)=T
      V=VC*FV(G)
      A(I)=T
      C(I)=V
      VS=2.*COSA*V
      IF(OPTION.LE.0.) WRITE(6,610) T,V,VS
```

```
      T=T+DT
   45 CONTINUE
      N=10
      IF(IABS(M-M1).LT.3) GO TO 55
      T=A(2)-0.8*DA
      IF(T.LE.0.) T=DA/5.
      DT=DA/3.
      DO 50 I=11,16
      G(1)=T
      V=VC*FV(G)
      A(I)=T
      C(I)=V
      VS=2.*COSA*V
      IF(OPTION.LE.0.) WRITE(6,610) T,V,VS
      T=T+DT
   50 CONTINUE
      N=16
   55 CONTINUE
      DO 75 JJ=1,6
      CALL XMAX(C,N,M,M1)
      IF(JJ.LT.3) GO TO 62
      IF(ABS((C(M)-C(M1))/C(M)).LT.0.001) GO TO 110
      IF(JJ.EQ.6) GO TO 120
   62 N=10
      T1=A(M)
      T2=A(M1)
      V1=C(M)
      V2=C(M1)
      A(9)=T1
      A(10)=T2
      C(9)=V1
      C(10)=V2
      DT=ABS(T1-T2)/5.
      II=1
      DO 70 I=1,8
      T=T1+DT*FLOAT((I-10)/2*II)
      IF (T .LE. 0.0) GO TO 64
      G(1)=T
      V=VC*FV(G)
      VS=2.*COSA*V
      GO TO 66
C     WHEN T IS LESS THAN ZERO SET TO ZERO.
   64 T = 0.0
      V = 0.0
   66 IF (OPTION .LE. 0.0) WRITE (6,610) T,V,VS
      A(I)=T
      C(I)=V
      II=-1*II
   70 CONTINUE
   75 CONTINUE
  110 V=C(M)
      T=A(M)
      VS=2.*COSA*C(M)
      IF(OPTION.LE.0.) WRITE(6,620) A(M),C(M),VS
      RETURN
  120 V=C(M)
      T=A(M)
      VS=2.*COSA*C(M)
      VS1=2.*COSA*C(M1)
      WRITE(6,630) T,V,VS,A(M1),C(M1),VS1
      RETURN
C
C
  580 FORMAT(1H1,10X,30HTRANSLATIONAL VELOCITY PROGRAM )
```

```
  590 FORMAT(1H0,5X,45HITERATION FOR PEAK TRANSLATIONAL VELOCITY PTV //
     1 12X,9HTIME(SEC),8X,16HVELOCITY(FT/SEC) ,3X,25HVERTICAL VELOCITY(F
     2T/SEC) /29X,16HTARGET SUBMERGED,7X,17HTARGET AT SURFACE )
  600 FORMAT(1H0,5X,23HINPUT TO SUBROUTINE PTV // 10X,
     1 45HTIMER2,T3,T4,T5,RAD,PTS,OPTION,COSA,RHOW,CWAT //1P5E14.5/
     2 1P5E14.5 )
  610 FORMAT(1P3E22.6)
  620 FORMAT(1H0,6X,20H******************** ,9X,3HPTV,19X,3HPTV//
     1 1P3E22.6)
  630 FORMAT(1H0,42H*** WARNING ITERATION DID NOT CONVERGE *** ,5X,
     1 35HMAXIMUM AND NEAREST VALUE ARE GIVEN //
     1 12X,9HTIME(SEC),8X,16HVELOCITY(FT/SEC) ,3X,25HVERTICAL VELOCITY(F
     2T/SEC) /29X,16HTARGET SUBMERGED,7X,17HTARGET AT SURFACE /
     3 (1P3E22.6))
C
      END



      FUNCTION FV(G)
C
C     THIS SUBPROGRAM SETS UP THE INTEGRATION FOR
C     THE TRANSLATIONAL VELOCITY V
C
      DIMENSION G(6)
      EXTERNAL F1
      DATA N/18/
C
      NN=FLOAT(N)*G(1)*G(2)/8.
      NN=MAX0(NN,8)
      NN=MIN0(NN,N)
      X=G(1)-8./G(2)
      IF(X.GT.G(3)) GO TO 43
      Z1=G(6)
      IF(X.GT.0.) Z1=SQRT(G(3)-X)
      IF(G(1).GT.G(3)) GO TO 40
      G(4)=-1.0
      Z2=SQRT(G(3)-G(1))
C     INTEGRATION FOR T .LE. TIMER2
      FV=-FGI(Z1,Z2,NN,F1,G)
      RETURN
   40 Z2=0.
      Z3=SQRT(G(1)-G(3))
      IF(G(3).EQ.0.) GO TO 45
      G(4)=-1.0
      N1=Z1/(Z1+Z3)*FLOAT(NN)+2.0
      NNN=Z3/(Z1+Z3)*FLOAT(NN)+2.0
C     INTEGRATION FOR INTERVAL WHICH INCLUDES TIMER2
      V1=-FGI(Z1,Z2,N1,F1,G)
      G(4)=1.0
      V2=FGI(Z2,Z3,NNN,F1,G)
      FV=V1+V2
      RETURN
   43 Z2=SQRT(X-G(3))
      Z3=SQRT(G(1)-G(3))
   45 G(4)=1.0
C     INTEGRATION FOR T LARGER THAN TIMER2 BUT THE
C     INTERVAL DOES NOT INCLUDE TIMER2.
      FV=FGI(Z2,Z3,NN,F1,G)
      RETURN
      END
```

```
      FUNCTION F1(Z,G)
C
C     THIS SUBPROGRAM CALCULATES THE PRODUCT INCIDENT PRESSURE *
C     REDUCED STEP WAVE ACCELERATION BY CALLING THE INTERPOLATION
C     PROGRAMS VTAB AND PTAB.
C
      DIMENSION QX(1000),QY(1000),IS(2)
      DIMENSION G(6),QQX(120),QQY(120)
      COMMON /QXY/QX,QY
      COMMON /QIS/IS
C
C     REDUCED STEP WAVE ACCELERATION OF A CYLINDER
C
      DATA (QQX(I),I=1,106) /0.,.0125,.025,.0375,.050,.075,.100,
     1 .125,.150,.175,.200,.225,.250,.275,.300,.325,.350,.375,
     2 .4000,.425,.450,.475,.500,.525,.550,.575,.600,.625,.650,
     3 .675,.700,.725,.750,.775,.800,.825,.850,.875,.900,.925,.950,
     4 .975,1.00,1.05,1.10,1.15,1.20,1.25,1.30,1.35,1.40,1.45,
     5 1.50,1.55,1.60,1.65,1.70,1.75,1.80,1.85,1.90,1.95,2.00,
     6 2.05,2.10,2.15,2.20,2.25,2.30,2.35,2.40,2.45,2.50,2.55,
     7 2.60,2.65,2.70,2.75,2.80,2.85,2.90,3.00,3.10,3.2,3.3,3.4,
     8 3.5,3.6,3.7,3.8,3.9,4.0,4.2,4.4,4.6,4.8,5.0,5.25,5.50,
     9 5.75,6.00,6.25,6.5,7.0,7.5,8.0 /
      DATA (QQY(I),I=1,60) / 0.0, .198193,.275935,.332694,.378180,
     1 .448836,.502189,.544000,.577342,.604111,.625589,.642701,
     2 .656143,.666457,.674079,.679365,.682612,.684070,.683955,
     3 .682452,.679721,.675904,.671127,.665499,.659120,.652078,
     4 .644453,.636315,.627730,.618755,.609444,.599844,.589999,
     5 .579949,.569730,.559374,.548913,.538372,.527777,.517151,
     6 .506515,.495887,.485284,.464215,.443417,.422977,.402968,
     7 .383447,.364460,.346042,.328218,.311008,.294424,.278471,
     8 .263152,.248465,.234404,.220960,.208124,.195881 /
      DATA (QQY(I),I=61,106) / .184219,.173122,.162573,.152555,
     1 .143051,.134041,.125509,.117435,.109801,.102590,.095782,
     2 .089361,.083308,.077608,.072242,.067196,.062453,.057999,
     3 .053818,.049897,.046221,.039556,.033725,.028637,.024209,
     4 .020368,.017044,.014177,.011712,.009599,.007795,.006260,
     5 .003863,.002172,.001009,.000230,-0.000267,-0.000619,
     6 -0.000774,-0.000804,-0.000767,-0.000696,-0.000606,
     7 -0.000430,-0.000297,-0.000206 /
C
      IF(G(4).GT.0.) GO TO 20
      X=G(3)-Z*Z
      GO TO 30
   20 X=G(3)+Z*Z
   30 XD=(G(1)-X)*G(2)
      IF(Z.GT.G(5)) GO TO 35
      P=PTAB(X,QX,QY,IS(2))
      GO TO 40
   35 P=VTAB(X,QX,QY,IS(2))
   40 F1=Z*P*VTAB(XD,QQX,QQY,IS(1))
      RETURN
      END
```

```
      SUBROUTINE XMAX(B,N,M,M1)
C
C
C     THIS SUBPROGRAM DETERMINES THE LOCATIONS OF THE TWO LARGEST
C     ABSOLUTE VALUES OF MEMBERS OF THE B ARRAY.
C
C
      DIMENSION B(50)
      X=ABS(B(1))
      M=1
      DO 10 I=2,N
      IF(ABS(B(I)).LT.X) GO TO 10
      M=I
      X=ABS(B(M))
   10 CONTINUE
      M1=1
      IF(M.EQ.1) M1=2
      X=ABS(B(M1))
      DO 20 I=2,N
      IF(ABS(B(I)).LT.X) GO TO 20
      IF(I.EQ.M) GO TO 20
      M1=I
      X=ABS(B(M1))
   20 CONTINUE
      RETURN
      END

      FUNCTION VTAB(X,Y,Z,K)
C
C     THIS SUBPROGRAM PERFORMS A SECOND ORDER LAGRANGIAN INTERPOLATION
C
C     THE INDEPENDENT VARIABLE IS STORED IN THE Y ARRAY IN INCREASING
C     ORDER.   THE DEPENDENT VARIABLE IS STORED IN THE Z ARRAY.
C     X IS THE POINT AT WHICH THE FUNCTION IS TO BE EVALUATED.
C     K IS THE NUMBER OF THE ELEMENT IN THE Y ARRAY WHICH IS FIRST
C     COMPARED WITH X.
C
C
      DIMENSION Y(1000),Z(1000)
      IF(X.LE.0.) GO TO 50
      DO 10 I=K,1000
      J=I
      IF(Y(I).GT.X) GO TO 20
   10 CONTINUE
   20 J=MAX0(3,J-1)
      DO 30 I=1,1000
      IF(Y(J).LT.X) GO TO 40
      J=J-1
      IF(J.LT.3) GO TO 40
   30 CONTINUE
   40 K=J+1
      IF(Z(J).EQ.Z(K)) GO TO 60
      L=J-1
      A=(X-Y(K))/(Y(J)-Y(L))
      C=(X-Y(L))/(Y(K)-Y(J))
      IF((A.LT.-5.0).OR.(C.GT.5.0)) GO TO 60
      B=(X-Y(J))/(Y(K)-Y(L))
      VTAB=C*(B*Z(K)-A*Z(J))+A*B*Z(L)
      RETURN
   50 VTAB=0.
      RETURN
   60 VTAB=Z(J)+(X-Y(J))*(Z(K)-Z(J))/(Y(K)-Y(J))
      RETURN
      END
```

```
      FUNCTION PTAB(X,Y,Z,K)
C
C
C     THIS SUBPROGRAM PERFORMS A SECOND ORDER LAGRANGIAN INTERPOLATION
C     WITH PROVISIONS FOR HANDLING A SINGULARITY.
C     FUNCTION ARGUMENTS ARE THE SAME AS IN VTAB .
C
C
      DIMENSION Y(1000),Z(1000)
      IF(X.LE.0.) GO TO 50
      DO 10 I=K,1000
      J=I
      IF(Y(I).GT.X) GO TO 20
   10 CONTINUE
   20 J=MAX0(3,J-1)
      DO 30 I=1,1000
      IF(Y(J).LT.X) GO TO 40
      J=J-1
      IF(J.LT.3) GO TO 40
   30 CONTINUE
   40 J=J+1
      JJ=J
C
C     THE FOLLOWING THREE STATEMENTS PROVIDE FOR EXTRAPOLATION
C     AROUND A SINGULARITY.
C
      IF(ABS(Z(J)).GT.1.0E20)JJ=J-2
      IF(ABS(Z(J-1)).GT.1.0E20)JJ=J+1
      IF((JJ.EQ.J).AND.(ABS(Z(J-2)).LT.1.0E20)) JJ=J-1
C
      J=JJ
      K=J+1
      IF(Z(J).EQ.Z(K)) GO TO 60
      L=J-1
      A=(X-Y(K))/(Y(J)-Y(L))
      C=(X-Y(L))/(Y(K)-Y(J))
      IF((A.LT.-5.0).OR.(C.GT.5.0)) GO TO 60
      B=(X-Y(J))/(Y(K)-Y(L))
      PTAB=C*(B*Z(K)-A*Z(J))+A*B*Z(L)
      RETURN
   50 PTAB=0.
      RETURN
   60 PTAB=Z(J)+(X-Y(J))*(Z(K)-Z(J))/(Y(K)-Y(J))
      RETURN
      END
```

APPENDIX B
SAMPLE PROGRAM OUTPUTS

TABLE B.1 FULL OUTPUT FOR A SPHERICAL WAVE BOTTOM REFLECTION

```
                          BOTTOM REFLECTION          DATE   06/29/71
                          RUN NUMBER     I
                            INPUT

DEPTH OF WATER IN FT                                                         BIGH=   .20000000E+04
DEPTH OF EXPLOSION IN FT                                                     D=   .70000000E+03
DEPTH OF GAUGE IN FT                                                         DGAU=   .80000000E+03
HORIZONTAL DISTANCE BETWEEN CHARGE AND GAUGE IN FT                           SMALLR=   .70000000E+04
WEIGHT OF EXPLOSIVE CHARGE IN LB (OR KT)                                     WCH=   .10000000E+02
VELOCITY OF SOUND IN WATER IN FT/SEC                                         CWATER=   .49000000E+04
VELOCITY OF SOUND IN BOTTOM IN FT/SEC                                        CBOT=   .52000000E+04
VELOCITY OF SHEARWAVE IN FT/SEC                                              CSHEAR=  0.
DENSITY OF WATER IN GM/CC                                                    RHOWAT=   .10300000E+01
DENSITY OF BOTTOM IN GM/CC                                                   RHOBOT=   .16600000E+01
COEFFICIENT OF SW PRESSURE FORMULA IN PSI                                    PRECOF=   .43800000E+07
PRINT OUT CONTROL PARAMETER (Z5.GT.0. FOR SHORTER PRINT OUT)                 Z5=   -0.
EXPONENT OF SW PRESSURE FORMULA                                              PREEXP=   .11300000E+01
COEFFICIENT OF SW TIME CONSTANT FORMULA IN SECONDS                           THECOE=   .22740000E-02
EXPONENT OF SW TIME CONSTANT FORMULA                                         THEEXP=  -.22000000E+00
NUMBER OF SUBDIVISIONS OF THETA                                              STEPS=   .40000000E+01
DURATION AFTER DIRECT ARRIVAL IN MULTIPLES OF THETA                          DURAT=   .50400981E+01
DESIRED RATIO BETWEEN INCIDENT AND CRITICAL ANGLE                            THOVAL= -0.
SCALING PARAMETER FOR Y-AXIS (PSI PER INCH OF GRAPH)                         X1=   .10000000E+03
SCALING PARAMETER FOR X-AXIS (MICROSECONDS PER INCH OF GRAPH)                X2=   .10000000E+05
SLOPE OF BOTTOM IN DEGREES                                                   SLOPE= -0.
PARAMETER THAT SELECTS THEORY                                                Z1= -0.
ARRIVAL TIME OF GROUND WAVE IN MICROSECONDS                                  Z2= -0.
PLOT CONTROL PARAMETER (Z3 = 0. MEANS PLOTS ARE WANTED)                      Z3=   .10000000E+01
CYLINDER RADIUS IN FT                                                        RADIUS=   .22000000E+02
PRINT CONTROL PARAMETER (FULL PRINT OUT IN SUBROUTINE PTV IF APRINT.LE.0.)   APRINT=  0.

                          CHARACTERISTIC MAGNITUDES

ANGLE OF INCIDENT WAVE IN DEGREES                                            THE=   .70346201E+02
VELOCITY OF STONLEY WAVE IN FT/SEC                                           CTSON= -0.
POISSON RATIO                                                                POISR=   .50000000E+00
REDUCED TIME OF SURFACE REFLECTION                                           RS=   .10225972E+01
CRITICAL ANGLE OF COMPRESSION WAVE IN DEGREES                                ALPHA=   .70442811E+02
ANGLE OF PRESSURE WAVE IN BOTTOM IN DEGREES                                  THEONE=   .88014453E+02
REFLECTION COEFFICIENT                                                       CR=   .88638002E+00
ANGLE OF SHEARWAVE IN BOTTOM IN DEGREES                                      ANGA= -0.
ANGLE OF PHASESHIFT IN DEGREES                                               EE=  0.
REDUCED TIME OF PRECURSOR ARRIVAL                                            D2R2=   .10617537E+01
REDUCED TIME OF PEAK OF BOTTOM REFLECTED WAVE                                R2=   .10617537E+01
SLANT DISTANCE BETWEEN CHARGE AND GAUGE=CHARACTERISTIC LENGTH IN FT.         RACTU =   .70007142E+04
REDUCED SLANT DISTANCE (RACTU/WCH**1/3)                                      REDR=   .32494437E+04
CHARACTERISTIC TIME=RACTU/CWATER IN SECONDS.                                 TACT=   .14287172E+01
CHARACTERISTIC PRESSURE=FREE WATER SW PEAK PRESSURE IN PSI                   PACT=   .47111824E+03
REDUCED TIME CONSTANT OF INCIDENT WAVE                                       THETA=   .20313067E-01
ACTUAL SW TIME CONSTANT IN MILLISECONDS                                      THET=  .29021628E+02
REDUCED TIME CONSTANT OF BOTTOM REFLECTED WAVE                               THETAR=   .20582624E-01
BOTTOM REFLECTED WAVE TIME CONSTANT IN MILLISECONDS                          THETR=   .29406749E+02

                          CONSTANTS OF THE CALCULATION
  SMALLH          DEZERO          D2              COSAL           COSTH           SINTH

.1300000E+04   -.1000000E+03   .3571064E+00   .3347480E+00   .3363364E+00   .9417419E+00
```

TABLE B.1 CONTINUED

ROSENBAUM METHOD
FAST NON-RIGID BOTTOM

DT	EDT
.2205490E-02	.8983882E+00

REDUCED TIME T SECOND ROW THIRD ROW	STEPWAVE RESPONSE STPW PHOT RESIDUE	CONVOLUTION- FI/THETA PS REDUCED IMPULSE	PD VMID REDUCED EFLUX	TIME SECONDS PRE PCSIMP	PRESSURE PSI	IMPULSE ENERGY FLUX REDUCED PUSIMP
.1000000E+01	0.	0.	.4711182E+03	0.	.4711182E+03	0.
	0.	0.	0.	0.		0.
	0.	0.	0.	0.		0.
.1004411E+01	0.	0.	.3791604E+03	.6302043E-02	.3791604E+03	0.
	0.	0.	0.	0.		0.
	0.	0.	0.	0.		0.
.1008822E+01	0.	0.	.3051518E+03	.1260409E-01	.3051518E+03	.4816675E+01
	0.	0.	0.	0.		.1606213E+00
	0.	.2235703E+01	.7455382E-01	.4816675E+01		.2235703E+01
.1013233E+01	0.	0.	.2455890E+03	.1890613E-01	.2455890E+03	.4816675E+01
	0.	0.	0.	0.		.1606213E+00
	0.	.2235703E+01	.7455382E-01	.4816675E+01		.2235703E+01
.1017644E+01	0.	0.	.1976523E+03	.2520817E-01	.1976523E+03	.7936523E+01
	0.	0.	0.	0.		.2280082E+00
	0.	.3683808E+01	.1058320E+00	.7936523E+01		.3683808E+01
.1022055E+01	0.	0.	.1590725E+03	.3151021E-01	.1590725E+03	.7936523E+01
	0.	0.	0.	0.		.2280082E+00
	0.	.3683808E+01	.1058320E+00	.7936523E+01		.3683808E+01
.1026466E+01	0.	0.	.1280230E+03	.3781226E-01	-.2520864E+03	.9158816E+01
	0.	-.3801094E+03	0.	0.		.2418550E+00
	0.	.4251146E+01	.1122591E+00	.9688369E+01		.4496943E+01
.1030877E+01	0.	0.	.1030341E+03	.4411430E-01	-.2032497E+03	.9158816E+01
	0.	-.3062838E+03	0.	0.		.2418550E+00
	0.	.4251146E+01	.1122591E+00	.9688369E+01		.4496943E+01
.1035288E+01	0.	0.	.8292281E+02	.5041634E-01	-.1638740E+03	.6577165E+01
	0.	-.2467968E+03	0.	0.		.1957243E+00
	0.	.3052850E+01	.9084715E-01	.9688369E+01		.4496943E+01
.1039699E+01	0.	0.	.6673705E+02	.5571838E-01	-.1321264E+03	.6577165E+01
	0.	-.1988634E+03	0.	0.		.1957243E+00
	0.	.3052850E+01	.9084715E-01	.9688369E+01		.4496943E+01
.1044110E+01	0.	0.	.5371061E+02	.6302043E-01	-.1065292E+03	.4898913E+01
	0.	-.1602398E+03	0.	0.		.1762299E+00
	0.	.2273874E+01	.8179866E-01	.9688369E+01		.4496943E+01
.1048521E+01	0.	0.	.4322680E+02	.6932247E-01	-.8589092E+02	.4898913E+01
	0.	-.1291177E+03	0.	0.		.1762299E+00
	0.	.2273874E+01	.8179866E-01	.9688369E+01		.4496943E+01

TABLE B.1 CONTINUED

.1052932E+01	0. 0. 0.	0. -.1040402E+03 .1767488E+01	.3478933E+02 0. .7797489E-01	.7562451E-01 0. .9688369E+01	-.6925090E+02	.3807938E+01 .1679918E+00 .4496943E+01
.1057343E+01	0. 0. 0.	0. -.8383333E+02 .1767488E+01	.2799878E+02 0. .7797489E-01	.8192655E-01 0. .9688369E+01	-.5583455E+02	.3807938E+01 .1679918E+00 .4496943E+01
		ARRIVAL OF GROUNDWAVE PEAK				
.1061754E+01	.8348264E+00 .3902501E+03 0.	0. -.6755106E+02 .1818818E+01	.2253368E+02 0. .8651140E-01	.8822860E-01 0. .1041359E+02	.3452327E+03	.3918525E+01 .1863832E+00 .4833562E+01
.1066165E+01	.5128732E+00 .1969325E+03 0.	.9159359E-01 -.5443117E+02 .1818814E+01	.1813532E+02 .5708848E+00 .8651140E-01	.9453064E-01 .5128732E+00 .1041359E+02	.1606366E+03	.3918525E+01 .1863832E+00 .4833562E+01
.1070576E+01	.4508035E+00 .1331290E+03 0.	.1660127E+00 -.4385944E+02 .2883225E+01	.1459547E+02 .4768147E+00 .1060427E+00	.1008327E+00 .4508035E+00 .1270679E+02	.1038651E+03	.6211721E+01 .2284621E+00 .5897969E+01
.1074987E+01	.4142390E+00 .9217797E+02 0.	.2170511E+00 -.3534097E+02 .2883225E+01	.1174657E+02 .4306137E+00 .1060427E+00	.1071347E+00 .4142390E+00 .1270679E+02	.6458357E+02	.6211721E+01 .2284621E+00 .5897969E+01
.1079398E+01	.3888844E+00 .6378958E+02 0.	.2524272E+00 -.2847698E+02 .3295638E+01	.9453761E+01 .4005603E+00 .1086900E+00	.1134368E+00 .3888864E+00 .1359531E+02	.4476635E+02	.7100237E+01 .2341655E+00 .6310382E+01
.1083809E+01	.3698623E+00 .4351478E+02 0.	.2767770E+00 -.2294613E+02 .3295638E+01	.7608467E+01 .3787600E+00 .1086900E+00	.1197388E+00 .3698623E+00 .1359531E+02	.2817912E+02	.7100237E+01 .2341655E+00 .6310382E+01
.1088220E+01	.3548863E+00 .2884579E+02 0.	.2931791E+00 -.1848944E+02 .3465261E+01	.6123345E+01 .3619620E+00 .1091466E+00	.1260409E+00 .3548863E+00 .1396074E+02	.1647967E+02	.7465677E+01 .2351493E+00 .6480004E+01
.1092631E+01	.3427066E+00 .1817431E+02 0.	.3038280E+00 -.1489842E+02 .3465261E+01	.4928142E+01 .3445025E+00 .1091466E+00	.1323429E+00 .3427066E+00 .1396074E+02	.8204032E+01	.7465677E+01 .2351493E+00 .6480004E+01
.1097042E+01	.3325626E+00 .1041336E+02 0.	.3102863E+00 -.1200482E+02 .3515641E+01	.3966215E+01 .3374157E+00 .1091924E+00	.1386449E+00 .3325626E+00 .1406929E+02	.2374752E+01	.7574220E+01 .2352479E+00 .6530385E+01
.1101453E+01	.3239583E+00 .4794315E+01 0.	.3137022E+00 -.9673223E+01 .3515641E+01	.3192047E+01 .3280921E+00 .1091924E+00	.1449470E+00 .3239583E+00 .1406929E+02	-.1686862E+01	.7574220E+01 .2352479E+00 .6530385E+01
.1105864E+01	.3165532E+00 .7616631E+00 0.	.3149234E+00 -.7794471E+01 .3507025E+01	.2568989E+01 .3201229E+00 .1091902E+00	.1512490E+00 .3165532E+00 .1407428E+02	-.4463819E+01	.7555657E+01 .2352432E+00 .6532701E+01

TABLE B.1 CONTINUED

TRANSLATIONAL VELOCITY PROGRAM

INPUT TO SUBROUTINE PTV

TIMER2,T3,T4,T5,RAD,PTS,OPTION,COSA,RHOW,CWAT

0.	-6.30204E-03	0.	6.30204E-02	2.20000E+01
3.00000E+01	0.	3.36336E-01	1.03000E+00	4.90000E+03

ITERATION FOR PEAK TRANSLATIONAL VELOCITY PTV

TIME(SEC)	VELOCITY(FT/SEC) TARGET SUBMERGED	VERTICAL VELOCITY(FT/SEC) TARGET AT SURFACE
1.086559E-03	6.525452E-01	4.389494E-01
3.259677E-03	2.147045E+00	1.444259E+00
5.432795E-03	2.922026E+00	1.965567E+00
7.605914E-03	3.073522E+00	2.067475E+00
9.779032E-03	2.887512E+00	1.942351E+00
1.195215E-02	2.592360E+00	1.743810E+00
1.412527E-02	2.320794E+00	1.561135E+00
1.629839E-02	2.068548E+00	1.391456E+00
1.847150E-02	1.831783E+00	1.232191E+00
2.064462E-02	1.620060E+00	1.089770E+00
2.281774E-02	1.429563E+00	9.616284E-01
2.499086E-02	1.259587E+00	8.472898E-01
2.716398E-02	1.109541E+00	7.463583E-01
2.933709E-02	9.757967E-01	6.563919E-01
3.151021E-02	8.567997E-01	5.763459E-01
3.368333E-02	7.511928E-01	5.053070E-01
3.585645E-02	6.566918E-01	4.417387E-01
3.802957E-02	5.723656E-01	3.850148E-01
4.020269E-02	4.972796E-01	3.345064E-01
4.237580E-02	4.297510E-01	2.890818E-01
4.454892E-02	3.693076E-01	2.484232E-01
4.672204E-02	3.152316E-01	2.120477E-01
4.889516E-02	2.666219E-01	1.793493E-01
5.106828E-02	2.231784E-01	1.501260E-01
5.324139E-02	1.842856E-01	1.239639E-01
5.541451E-02	1.493711E-01	1.004779E-01
5.758763E-02	1.182308E-01	7.953062E-02
5.976075E-02	9.038491E-02	6.079947E-02
6.193387E-02	6.546200E-02	4.403451E-02
3.694301E-03	2.363885E+00	1.590121E+00
4.780860E-03	2.767551E+00	1.861656E+00
5.867419E-03	2.992797E+00	2.013173E+00
6.953978E-03	3.075552E+00	2.068840E+00
8.040537E-03	3.054987E+00	2.055006E+00
9.127096E-03	2.963759E+00	1.993640E+00
1.021366E-02	2.831359E+00	1.904578E+00
1.130021E-02	2.682011E+00	1.804116E+00
6.432430E-03	3.050738E+00	2.052148E+00
7.475526E-03	3.076577E+00	2.069530E+00
6.562817E-03	3.059309E+00	2.057914E+00
7.345139E-03	3.078365E+00	2.070733E+00
6.693204E-03	3.066342E+00	2.062645E+00
7.214752E-03	3.078826E+00	2.071043E+00
6.823591E-03	3.071737E+00	2.066274E+00
7.084365E-03	3.077909E+00	2.070426E+00
7.110443E-03	3.078206E+00	2.070625E+00
7.319062E-03	3.078566E+00	2.070867E+00
7.136520E-03	3.078445E+00	2.070787E+00
7.292985E-03	3.078712E+00	2.070966E+00

TABLE B.1 CONTINUED

7.162597E-03	3.078628E+00	2.070909E+00
7.266907E-03	3.078805E+00	2.071028E+00
7.188675E-03	3.078755E+00	2.070995E+00
7.240830F-03	3.078843E+00	2.071054E+00
********************	PTV	PTV
7.240830F-03	3.078843E+00	2.071054E+00

TABLE B.2 SHORT OUTPUT FOR A SPHERICAL WAVE BOTTOM REFLECTION

BOTTOM REFLECTION DATE 06/29/71
RUN NUMBER 2
INPUT

DEPTH OF WATER IN FT	BIGH= .54064000E+01
DEPTH OF EXPLOSION IN FT	D= .74166000E+00
DEPTH OF GAUGE IN FT	DGAU= .13000000E+01
HORIZONTAL DISTANCE BETWEEN CHARGE AND GAUGE IN FT	SMALLR= .39416600E+01
********** CALCULATION GEOMETRY CHANGED FOR SLOPING BOTTOM	
DEPTH OF WATER IN FT	BIGH= .40401293E+01
DEPTH OF GAUGE IN FT	DGAU= .39236405E+01
HORIZONTAL DISTANCE BETWEEN CHARGE AND GAUGE IN FT	SMALLR= .23923685E+01
WEIGHT OF EXPLOSIVE CHARGE IN LB (OR KT)	WCH= .12500000E-02
VELOCITY OF SOUND IN WATER IN FT/SEC	CWATER= .49000000E+04
VELOCITY OF SOUND IN BOTTOM IN FT/SEC	CBOT= .18500000E+05
VELOCITY OF SHEARWAVE IN FT/SEC	CSHEAR= .10200000E+05
DENSITY OF WATER IN GM/CC	RHOWAT= .99800000E+00
DENSITY OF BOTTOM IN GM/CC	RHOBOT= .27200000E+01
COEFFICIENT OF SW PRESSURE FORMULA IN PSI	PRECDE= .15400000E+05
PRINT OUT CONTROL PARAMETER (Z5.GT.0. FOR SHORTER PRINT OUT)	Z5= .100000E+01
EXPONENT OF SW PRESSURE FORMULA	PREEXP= .11300000E+01
COEFFICIENT OF SW TIME CONSTANT FORMULA IN SECONDS	THECOE= .75000000E-04
EXPONENT OF SW TIME CONSTANT FORMULA	THEEXP= -.22000000E+00
NUMBER OF SUBDIVISIONS OF THETA	STEPS= .10000000E+02
DURATION AFTER DIRECT ARRIVAL IN MULTIPLES OF THETA	DURAT= .46528584E+01
DESIRED RATIO BETWEEN INCIDENT AND CRITICAL ANGLE	THOVAL= 0.
SCALING PARAMETER FOR Y-AXIS (PSI PER INCH OF GRAPH)	X1= .10000000E+03
SCALING PARAMETER FOR X-AXIS (MICROSECONDS PER INCH OF GRAPH)	X2= .10000000E+02
SLOPE OF BOTTOM IN DEGREES	SLOPE= .45000000E+02
PARAMETER THAT SELECTS THEORY	Z1= -0.
ARRIVAL TIME OF GROUND WAVE IN MICROSECONDS	Z2= -0.
PLOT CONTROL PARAMETER (Z3 = 0. MEANS PLOTS ARE WANTED)	Z3= .10000000E+01
CYLINDER RADIUS IN FT	RADIUS=-0.
PRINT CONTROL PARAMETER (FULL PRINT OUT IN SUBROUTINE PTV IF APRINT.LE.0.)	APRINT= -0.

CHARACTERISTIC MAGNITUDES

ANGLE OF INCIDENT WAVE IN DEGREES	THE= .35013398E+02
VELOCITY OF STONLEY WAVE IN FT/SEC	CTSON= .48865514E+04
POISSON RATIO	POISR= .28162126E+00
REDUCED TIME OF SURFACE REFLECTION	RS= .11150537E+01
CRITICAL ANGLE OF COMPRESSION WAVE IN DEGREES	ALPHA= .15358929E+02
CRITICAL ANGLE OF SHEARWAVE IN DEGREES	BETHA= 28.711
REDUCED ARRIVAL TIME OF CRITICALLY REFRACTED SHEAR WAVE	SHD2R2= .10410370E+01
ANGLE OF PRESSURE WAVE IN BOTTOM IN DEGREES	THEONE= -0.
REFLECTION COEFFICIENT	CR= .10000000E+01
ANGLE OF SHEARWAVE IN BOTTOM IN DEGREES	ANGA= -0.
ANGLE OF PHASESHIFT IN DEGREES	EE= -.47801586E+02
REDUCED TIME OF PRECURSOR ARRIVAL	D2R2= .98634537E+00
REDUCED TIME OF PEAK OF BOTTOM REFLECTED WAVE	R2= .10473669E+01
SLANT DISTANCE BETWEEN CHARGE AND GAUGE=CHARACTERISTIC LENGTH IN FT.	RACTU = .39810083E+01
REDUCED SLANT DISTANCE (RACTU/WCH**1/3)	REDR= .36956407E+02
CHARACTERISTIC TIME=RACTU/CWATER IN SECONDS.	TACT= .81245067E-03
CHARACTERISTIC PRESSURE=FREE WATER SW PEAK PRESSURE IN PSI	PACT= .26063414E+03
REDUCED TIME CONSTANT OF INCIDENT WAVE	THETA= .22001857E-01
ACTUAL SW TIME CONSTANT IN MILLISECONDS	THET= .17875424E-01
REDUCED TIME CONSTANT OF BOTTOM REFLECTED WAVE	THETAR= .22227012E-01
BOTTOM REFLECTED WAVE TIME CONSTANT IN MILLISECONDS	THETR= .18058351E-01

CONSTANTS OF THE CALCULATION

SMALLH	DEZERO	O2	COSAL	COSTH	SINTH
.3298469E+01	-.318198[illegible]E+01	.8578124E+00	.9642855E+00	.8190180E+00	.5737678E+00

TABLE B.2 CONTINUED

ROSENBAUM METHOD
RIGID BOTTOM WITH FAST SHEAR WAVE

DT	EDT
.1052095E-02	.9537687E+00

REDUCED TIME T	PROT	ENERGY FLUX	PD	TIME SECONDS	PRESSURE PSI	IMPULSE
.9863454E+00	0.	0.	0.	-.1109371E-04	0.	0.
.9884496E+00	.2659025E+01	0.	0.	-.9384164E-05	.2659025E+01	0.
.9905537E+00	.3420556E+01	.2019876E-08	0.	-.7674613E-05	.3420556E+01	.8010188E-05
.9926579E+00	.3393037E+01	.2019876E-08	0.	-.5965062E-05	.3393037E+01	.8010188E-05
.9947621E+00	.3035006E+01	.5402798E-08	0.	-.4255512E-05	.3035006E+01	.1942298E-04
.9968663E+00	.2553975E+01	.5402799E-08	0.	-.2545961E-05	.2553975E+01	.1942298E-04
.9989705E+00	.2049203E+01	.7398414E-08	0.	-.8364102E-06	.2049203E+01	.2814175E-04

ARRIVAL OF DIRECT WAVE P = .2624486E+03

.1001075E+01	.1569388E+01	.7398414E-08	.2482092E+03	.8731405E-06	.2497786E+03	.2814175E-04
.1003179E+01	.1138287E+01	.1521177E-04	.2255710E+03	.2582691E-05	.2267093E+03	.7278453E-03
.1005283E+01	.7669901E+00	.1521177E-04	.2049975E+03	.4292242E-05	.2057645E+03	.7278453E-03
.1007387E+01	.4601681E+00	.2812630E-04	.1863005E+03	.6001793E-05	.1867607E+03	.1432481E-02
.1009491E+01	.2194434E+00	.2812630E-04	.1693088E+03	.7711343E-05	.1695282E+03	.1432481E-02
.1011596E+01	.4533097E-01	.3689289E-04	.1538668E+03	.9420894E-05	.1539121E+03	.2013036E-02
.1013700E+01	-.6153348E-01	.3689289E-04	.1398332E+03	.1113044E-04	.1397717E+03	.2013036E-02
.1015804E+01	-.9948836E-01	.4285207E-04	.1270796E+03	.1284000E-04	.1269801E+03	.2491698E-02
.1017908E+01	-.6501643E-01	.4285207E-04	.1154891E+03	.1454955E-04	.1154241E+03	.2491698E-02
.1020012E+01	.4820993E-01	.4691592E-04	.1049558E+03	.1625910E-04	.1050040E+03	.2886992E-02
.1022117E+01	.2506362E+00	.4691592E-04	.9538320E+02	.1796865E-04	.9563384E+02	.2886992E-02
.1024221E+01	.5588241E+00	.4970565E-04	.8668367E+02	.1967820E-04	.8724250E+02	.3214532E-02
.1026325E+01	.9987382E+00	.4970565E-04	.7877759E+02	.2138775E-04	.7977633E+02	.3214532E-02
.1028429E+01	.1611497E+01	.5164698E-04	.7159260E+02	.2309730E-04	.7320409E+02	.3487805E-02
.1030533E+01	.2464018E+01	.5164698E-04	.6506292E+02	.2480685E-04	.6752694E+02	.3487805E-02
.1032639E+01	.3670633E+01	.5303840E-04	.5912878E+02	.2651640E-04	.6279942E+02	.3719227E-02
.1034742E+01	.5440911E+01	.5303840E-04	.5373588E+02	.2822595E-04	.5917679E+02	.3719227E-02
.1036846E+01	.8203004E+01	.5410966E-04	.4883484E+02	.2993550E-04	.5703784E+02	.3922404E-02
.1038950E+01	.1300474E+02	.5410966E-04	.4438080E+02	.3164505E-04	.5738554E+02	.3922404E-02
.1041054E+01	.2434542E+02	.5515082E-04	.4033300E+02	.3335460E-04	.6467842E+02	.4122569E-02
.1041272E+01	.2826991E+02	.5515082E-04	.3993594E+02	.3353145E-04	.6820585E+02	.4122569E-02
.1041499E+01	.3261258E+02	.5529715E-04	.3954278E+02	.3370830E-04	.7215536E+02	.4146718E-02
.1041707E+01	.3663359E+02	.5529715E-04	.3915349E+02	.3388515E-04	.7578708E+02	.4146718E-02
.1041929E+01	.4140145E+02	.5547801E-04	.3876804E+02	.3406200E-04	.8016949E+02	.4173568E-02
.1042143E+01	.4659329E+02	.5547801E-04	.3838638E+02	.3423885E-04	.8497967E+02	.4173568E-02
.1042360E+01	.5162452E+02	.5570456E-04	.3800848E+02	.3441570E-04	.8963300E+02	.4203617E-02
.1042579E+01	.5823241E+02	.5570456E-04	.3763430E+02	.3459255E-04	.9586691E+02	.4203617E-02
.1042796E+01	.6437615E+02	.5599266E-04	.3726380E+02	.3476940E-04	.1016399E+03	.4237497E-02
.1043013E+01	.7075323E+02	.5599266E-04	.3689695E+02	.3494625E-04	.1076502E+03	.4237497E-02
.1043231E+01	.7839704E+02	.5635794E-04	.3653371E+02	.3512310E-04	.1149307E+03	.4275648E-02
.1043445E+01	.8617768E+02	.5635794E-04	.3617404E+02	.3529995E-04	.1223517E+03	.4275648E-02
.1043666E+01	.9362152E+02	.5682748E-04	.3581792E+02	.3547680E-04	.1294394E+03	.4318904E-02
.1043884E+01	.1011125E+03	.5682748E-04	.3546531E+02	.3565365E-04	.1365778E+03	.4318904E-02
.1044102E+01	.1077041E+03	.5741159E-04	.3511616E+02	.3583050E-04	.1428202E+03	.4367159E-02
.1044319E+01	.1127896E+03	.5741159E-04	.3477045E+02	.3600735E-04	.1475601E+03	.4367159E-02
.1044537E+01	.1142913E+03	.5808896E-04	.3442815E+02	.3618420E-04	.1487195E+03	.4419140E-02
.1044755E+01	.1108298E+03	.5808894E-04	.3408921E+02	.3636105E-04	.1449190E+03	.4419140E-02

NOT REPRODUCIBLE

TABLE B.2 CONTINUED

.1044072E+01	.1014409E+03	.5873911E-04	.3375362E+02	.3653790E-04	.1352025E+03	.4470049E-02
.1045190E+01	.5677902E+02	.5873911E-04	.3342132E+02	.3671476E-04	.1202003E+03	.4470049E-02
.1045408E+01	.6479978E+02	.5918675E-04	.3309230E+02	.3689161E-04	.9788308E+02	.4512133E-02
.1045625E+01	.3808709E+02	.5918675E-04	.3276651E+02	.3706846E-04	.7085361E+02	.4512133E-02
.1045843E+01	.8818527E+01	.5935067E-04	.3244394E+02	.3724531E-04	.4126247E+02	.4537043E-02
.1046061E+01	-.1956238E+02	.5935067E-04	.3212454E+02	.3742216E-04	.1256216E+02	.4537043E-02
.1046279E+01	-.4907707E+02	.5936165E-04	.3180828E+02	.3759901E-04	-.1527909E+02	.4541537E-02
.1046494E+01	-.7920288E+02	.5936165E-04	.3149514E+02	.3777586E-04	-.1527909E+02	.4541537E-02
.1046714E+01	-.1097522E+03	.5935433E-04	.3118508E+02	.3795271E-04	-.1527909E+02	.4536133E-02
.1046932E+01	-.1446154E+03	.5935433E-04	.3087807E+02	.3812956E-04	-.1527909E+02	.4536133E-02
.1047149E+01	-.1944872E+03	.5934701E-04	.3057409E+02	.3830641E-04	-.1527909E+02	.4530728E-02
.1047312E+01	-.2797102E+03	.5934701E-04	.3034806E+02	.3843905E-04	-.1527909E+02	.4530728E-02

****
ARRIVAL OF GROUNDWAVE PEAK(SINGULARITY)
****

.1047367E+01	-.2590708E+03	.5934696E-04	.3027309E+02	.3848326E-04	-.1527909E+02	.4528026E-02
.1047433E+01	-.1007562E+03	.5934696E-04	.3018274E+02	.3853668E-04	-.1527909E+02	.4528026E-02
.1047430E+01	-.2117358E+02	.5934694E-04	.2991334E+02	.3869695E-04	.8739761E+01	.4526472E-02
.1047893E+01	.1681353E+02	.5934694E-04	.2955787E+02	.3891064E-04	.4637140E+02	.4526472E-02
.1048156E+01	.3749709E+02	.5942983E-04	.2920662E+02	.3912434E-04	.6670371E+02	.4545058E-02
.1048419E+01	.5118760E+02	.5942983E-04	.2885955E+02	.3933803E-04	.8004714E+02	.4545058E-02
.1048682E+01	.6109520E+02	.5967050E-04	.2851660E+02	.3955172E-04	.8961180E+02	.4579000E-02
.1048945E+01	.6864280E+02	.5967050E-04	.2817772E+02	.3976542E-04	.9682052E+02	.4579000E-02
.1049208E+01	.7458572E+02	.6002425E-04	.2784287E+02	.3997911E-04	.1024286E+03	.4620266E-02
.1049471E+01	.7937233E+02	.6002425E-04	.2751200E+02	.4019281E-04	.1068843E+03	.4620266E-02
.1049734E+01	.8329073E+02	.6045616E-04	.2718507E+02	.4040650E-04	.1104751E+03	.4665885E-02
.1049997E+01	.8653366E+02	.6045616E-04	.2686201E+02	.4062019E-04	.1133957E+03	.4665885E-02
.1050260E+01	.8924116E+02	.6094269E-04	.2654280E+02	.4083389E-04	.1157840E+03	.4714311E-02
.1050523E+01	.9151358E+02	.6094269E-04	.2622738E+02	.4104758E-04	.1177410E+03	.4714311E-02
.1050786E+01	.9342703E+02	.6146747E-04	.2591571E+02	.4126128E-04	.1193427E+03	.4764607E-02
.1051049E+01	.9504017E+02	.6146747E-04	.2560774E+02	.4147497E-04	.1206479E+03	.4764607E-02
.1051312E+01	.9639911E+02	.6201863E-04	.2530343E+02	.4168866E-04	.1217025E+03	.4816153E-02
.1051575E+01	.9754074E+02	.6201863E-04	.2500274E+02	.4190236E-04	.1225435E+03	.4816153E-02
.1051838E+01	.9849492E+02	.6258734E-04	.2470562E+02	.4211605E-04	.1232005E+03	.4868513E-02
.1053942E+01	.1016359E+03	.6258734E-04	.2245232E+02	.4382560E-04	.1240883E+03	.4868513E-02
.1056047E+01	.1003978E+03	.6720299E-04	.2040453E+02	.4553515E-04	.1208023E+03	.5290405E-02
.1058151E+01	.9716918E+02	.6720299E-04	.1854351E+02	.4724470E-04	.1157127E+03	.5290405E-02
.1060255E+01	.9297357E+02	.7125532E-04	.1685223E+02	.4895425E-04	.1098258E+03	.5685584E-02
.1062359E+01	.8832727E+02	.7125532E-04	.1531521E+02	.5066380E-04	.1036425E+03	.5685584E-02
.1064463E+01	.8351625E+02	.7451497E-04	.1391837E+02	.5237336E-04	.9743462E+02	.6039935E-02
.1066568E+01	.7870772E+02	.7451497E-04	.1264893E+02	.5408291E-04	.9135665E+02	.6039935E-02
.1068472E+01	.7400205E+02	.7705043E-04	.1149527E+02	.5579246E-04	.8549732E+02	.6352417E-02
.1070776E+01	.6945961E+02	.7705043E-04	.1044683E+02	.5750201E-04	.7990644E+02	.6352417E-02
.1072880E+01	.6511577E+02	.7899123E-04	.9494014E+01	.5921156E-04	.7460978E+02	.6625793E-02
.1074984E+01	.6098975E+02	.7899123E-04	.8628102E+01	.6092111E-04	.6961785E+02	.6625793E-02
.1077089E+01	.5709018E+02	.8046486E-04	.7841167E+01	.6263066E-04	.6493134E+02	.6863997E-02
.1079193E+01	.5341860E+02	.8046486E-04	.7126004E+01	.6434021E-04	.6054460E+02	.6863997E-02
.1081297E+01	.4997185E+02	.8157958E-04	.6476069E+01	.6604976E-04	.5644792E+02	.7071171E-02
.1083401E+01	.4674366E+02	.8157958E-04	.5885412E+01	.6775931E-04	.5262907E+02	.7071171E-02
.1085505E+01	.4372576E+02	.8242194E-04	.5348627E+01	.6946886E-04	.4907438E+02	.7251265E-02
.1087610E+01	.4090862E+02	.8242194E-04	.4860800E+01	.7117841E-04	.4576942E+02	.7251265E-02
.1089714E+01	.3828203E+02	.8305904E-04	.4417465E+01	.7288796E-04	.4269950E+02	.7407889E-02
.1091818E+01	.3583547E+02	.8305904E-04	.4014565E+01	.7459751E-04	.3985003E+02	.7407889E-02
.1093922E+01	.3355835E+02	.8354200E-04	.3648413E+01	.7630706E-04	.3720677E+02	.7544258E-02
.1096026E+01	.3144028E+02	.8354200E-04	.3315655E+01	.7801662E-04	.3475593E+02	.7544258E-02
.1098130E+01	.2947109E+02	.8390935E-04	.3013247E+01	.7972617E-04	.3248434E+02	.7663194E-02
.1100235E+01	.2764102E+02	.8390935E-04	.2738421E+01	.8143572E-04	.3037944E+02	.7663194E-02
.1102339E+01	.2594072E+02	.9418999E-04	.2488660E+01	.8314527E-04	.2842938E+02	.7767153E-02
.1104443E+01	.2436129E+02	.8430495E-04	.2261679E+01	.8485482E-04	.2662297E+02	.7814210E-02

TABLE B.3 OUTPUT FOR A PLANE WAVE BOTTOM REFLECTION

```
                              BOTTOM REFLECTION          DATE    06/29/71
                              RUN NUMBER      3
                                  INPUT

OEPTH OF WATER IN FT                                                        BIGH=    .26042000E+01
DEPTH OF EXPLOSION IN FT                                                    D=   .14350000E+01
DEPTH OF GAUGE IN FT                                                        DGAU=    .24900000E+01
            GEOMETRY CHANGED SO THAT ARRIVAL TIME OF GROUNOWAVE IS Z2 =   .13500000E+02

OEPTH OF EXPLOSION IN FT                                                    D=   .14370658E+01
DEPTH OF GAUGE IN FT                                                        OGAU=    .24879342E+01
HORIZONTAL OISTANCE BETWEEN CHARGE AND GAUGE IN FT                          SMALLP=    .39580000E+01
WEIGHT OF EXPLOSIVE CHARGE IN LH (OR KT)                                    WCH=   .12500000E-02
VELOCITY OF SOUND IN WATER IN FT/SEC                                        CWATER=    .48700000E+04
VELOCITY OF SOUND IN BOTTOM IN FT/SEC                                       CBOT=   .58700000E+04
VELOCITY OF SHEARWAVE IN FT/SEC                                             CSHEAR=  0.
DENSITY OF WATER IN GM/CC                                                   RHOWAT=    .99800000E+00
DENSITY OF BOTTOM IN GM/CC                                                  RHOBOT=    .18600000E+01
COEFFICIENT OF SW PRESSURE FORMULA IN PSI                                   PRECOE=    .15400000E+05
PRINT OUT CONTROL PARAMETER (75.GT.0. FOR SHORTER PRINT OUT)                Z5=    .100000E+01
EXPONENT OF SW PRESSUPE FORMULA                                             PREEXP=    .11300000E+01
COEFFICIENT OF SW TIME CONSTANT FORMULA IN SECONOS                          THECOE=    .95000000E-04
EXPONENT OF SW TIME CONSTANT FORMULA                                        THEEXP=  -.22000000E+00
NUMBER OF SUBDIVISIONS OF THETA                                             STEPS=   .10000000E+02
DURATION AFTER DIRECT ARRIVAL IN MULTIPLES OF THETA                         DURAT=   .25925359E+01
DESIRED RATIO BETWEEN INCIDENT AND CRITICAL ANGLE                           THOVAL=  -.10000000E+01
SCALING PARAMETER FOR Y-AXIS (PSI PER INCH OF GRAPH)                        X1=   .10000000E+03
SCALING PAPAMETER FOR X-AXIS (MICROSECONDS PER INCH OF GRAPH)               X2=   .10000000E+02
SLOPE OF BOTTOM IN OEGREES                                                  SLOPE= -0.
PARAMETEP THAT SELECTS THEOPY                                               Z1=   .10000000E+01
APPIVAL TIME OF GROUND WAVE IN MICROSECONOS                                 Z2=   .13500000E+02
PLOT CONTROL PARAMETER (Z3 = 0. MEANS PLOTS ARE WANTEO)                     Z3=   .10000000E+01
CYLINDEP RADIUS IN FT                                                       RADIUS=-0.
PRINT CONTROL PARAMETER (FULL PRINT OUT IN SUBROUTINE PTV IF APRINT.LE.0.)  APRINT= -0.

                             CHARACTERISTIC MAGNITUOES

ANGLE OF INCIOENT WAVE IN OEGPEES                                           THE=   .72034497E+02
VELOCITY OF STONLEY WAVE IN FT/SEC                                          CTSON= -0.
POISSON RATIO                                                               POISR=   .50000000E+00
PEDUCED TIME OF SURFACE REFLECTION                                          RS=   .13611709E+01
CRITICAL ANGLE OF COMPRESSION WAVE IN DEGREES                               ALPHA=   .56062026E+02
ANGLE OF PRESSURE WAVE IN BOTTOM IN OEGREES                                 THEONE= -0.
REFLECTION COEFFICIENT                                                      CP=  .10000000E+01
ANGLE OF SHEARWAVE IN BOTTOM IN DEGREES                                     ANGA= -0.
ANGLE OF PHASESHIFT IN DEGPEES                                              EE=  .77981406E+02
PEDUCED TIME OF PRECUPSOR ARRIVAL                                           D2R2=   .97682869E+00
REDUCED TIME OF PEAK OF BOTTOM REFLECTEO WAVE                               R2=  .10160544E+01
SLANT DISTANCE BETWEEN CHARGE AND GAUGE=CHAPACTERISTIC LENGTH IN FT.        RACTU =  .40951299E+01
PEDUCED SLANT DISTANCE (RACTU/WCH**1/3)                                     REOR=   .38015818E+02
CHARACTERISTIC TIME=RACTU/CWATER IN SECONDS.                                TACT=   .84088909E-03
CHAPACTERISTIC PRESSUPE=FREE WATER SW PEAK PRESSURE IN PSI                  PACT=   .25244165E+03
REDUCED TIME CONSTANT OF INCIDENT WAVE                                      THETA=   .27094453E-01
ACTUAL SW TIME CONSTANT IN MILLISECONDS                                     THET=  .22783430E-01
REOUCED TIME CONSTANT OF BOTTOM REFLECTED WAVE                              THETAR=   .27189556E-01
BOTTOM PEFLECTED WAVE TIME CONSTANT IN MILLISECONDS                         THETR=   .22863401E-01

                              CONSTANTS OF THE CALCULATION
   SMALLH          DEZERO          02             COSAL           COSTH           SINTH

.1167134E+01   -.1050868E+01   .3133967E+00   .5582-54E+00   .3084447E+00   .9512423E+00
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TABLE B.3 CONTINUED

PLANE WAVE APPROXIMATION
ARONS-YENNIE APPROACH NON-RIGID BOTTOMS

REDUCED TIME T	BOTTOM REFLECTION PBOT	SHOCKWAVE PD	SURFACE REFLECTION PS	TIME SECONDS	TOTAL PRESSURE P (PSI)
.9768287E+00	.3559761E+02	0.	0.	-.1948450E-04	.3559761E+02
.9794437E+00	.3741375E+02	0.	0.	-.1728554E-04	.3741375E+02
.9820588E+00	.3944024E+02	0.	0.	-.1508657E-04	.3944024E+02
.9846738E+00	.4171822E+02	0.	0.	-.1288760E-04	.4171822E+02
.9872889E+00	.4430085E+02	0.	0.	-.1068864E-04	.4430085E+02
.9899039E+00	.4725831E+02	0.	0.	-.8489669E-05	.4725831E+02
.9925190E+00	.5068544E+02	0.	0.	-.6290702E-05	.5068544E+02
.9951340E+00	.5471418E+02	0.	0.	-.4091736E-05	.5471418E+02
.9977491E+00	.5953483E+02	0.	0.	-.1892769E-05	.5953483E+02
.1000000E+01	.6453371E+02	.2524417E+03	0.	0.	.3169754E+03
.1002615E+01	.7171971E+02	.2292158E+03	0.	.2198967E-05	.3009355E+03
.1005230E+01	.8109632E+02	.2081269E+03	0.	.4397934E-05	.2892232E+03
.1007845E+01	.9405649E+02	.1889783E+03	0.	.6596901E-05	.2830347E+03
.1010460E+01	.1137444E+03	.1715914E+03	0.	.8795868E-05	.2853358E+03
.1013075E+01	.1499189E+03	.1558042E+03	0.	.1099483E-04	.3057231E+03
.1013598E+01	.1618262E+03	.1528255E+03	0.	.1143463E-04	.3146517E+03
.1014121E+01	.1770567E+03	.1499037E+03	0.	.1187442E-04	.3269605E+03
.1014644E+01	.1978137E+03	.1470379E+03	0.	.1231421E-04	.3448515E+03
.1015167E+01	.2295034E+03	.1442268E+03	0.	.1275401E-04	.3737302E+03
.1015690E+01	.2933076E+03	.1414694E+03	0.	.1319380E-04	.4347770E+03
.1016054E+01	.2479390E+33	.1395809E+03	0.	.1350000E-04	.2479390E+33
.1016577E+01	.3046459E+03	.1369124E+03	0.	.1393979E-04	.4415582E+03
.1017100E+01	.2459064E+03	.1342949E+03	0.	.1437959E-04	.3802013E+03
.1017623E+01	.2102422E+03	.1317274E+03	0.	.1481938E-04	.3419696E+03
.1018146E+01	.1842524E+03	.1292090E+03	0.	.1525917E-04	.3134615E+03
.1018669E+01	.1636880E+03	.1267388E+03	0.	.1569897E-04	.2904268E+03
.1019192E+01	.1466344E+03	.1243158E+03	0.	.1613876E-04	.2709501E+03
.1019716E+01	.1320582E+03	.1219391E+03	0.	.1657855E-04	.2539973E+03
.1020239E+01	.1193354E+03	.1196079E+03	0.	.1701835E-04	.2389433E+03
.1022854E+01	.7279964E+02	.1086034E+03	0.	.1921731E-04	.1814030E+03
.1025469E+01	.4223667E+02	.9861135E+02	0.	.2141628E-04	.1408480E+03
.1028084E+01	.2035909E+02	.8953865E+02	0.	.2361525E-04	.1098977E+03
.1030699E+01	.4037982E+01	.8130067E+02	0.	.2581421E-04	.8533865E+02
.1033314E+01	-.8408369E+01	.7382063E+02	0.	.2801318E-04	.6541226E+02
.1035929E+01	-.1800837E+02	.6702879E+02	0.	.3021215E-04	.4902041E+02
.1038544E+01	-.2544547E+02	.6086182E+02	0.	.3241112E-04	.3541635E+02
.1041159E+01	-.3120062E+02	.5526225E+02	0.	.3461008E-04	.2406163E+02
.1043774E+01	-.3562645E+02	.5017786E+02	0.	.3680905E-04	.1455141E+02
.1046389E+01	-.3898950E+02	.4556126E+02	0.	.3900802E-04	.6571760E+01
.1049004E+01	-.4149596E+02	.4136941E+02	0.	.4120698E-04	-.1265407E+00
.1051619E+01	-.4330813E+02	.3756323E+02	0.	.4340595E-04	-.5744896E+01
.1054234E+01	-.4455562E+02	.3410724E+02	0.	.4560492E-04	-.1044838E+02
.1056849E+01	-.4534303E+02	.3096922E+02	0.	.4780388E-04	-.1437382E+02
.1059464E+01	-.4575551E+02	.2811990E+02	0.	.5000285E-04	-.1580826E+02
.1062079E+01	-.4586286E+02	.2553274E+02	0.	.5220182E-04	-.1580826E+02
.1064694E+01	-.4572262E+02	.2318361E+02	0.	.5440079E-04	-.1580826E+02
.1067309E+01	-.4538237E+02	.2105061E+02	0.	.5659975E-04	-.1580826E+02
.1069924E+01	-.4488166E+02	.1911385E+02	0.	.5879872E-04	-.1580826E+02

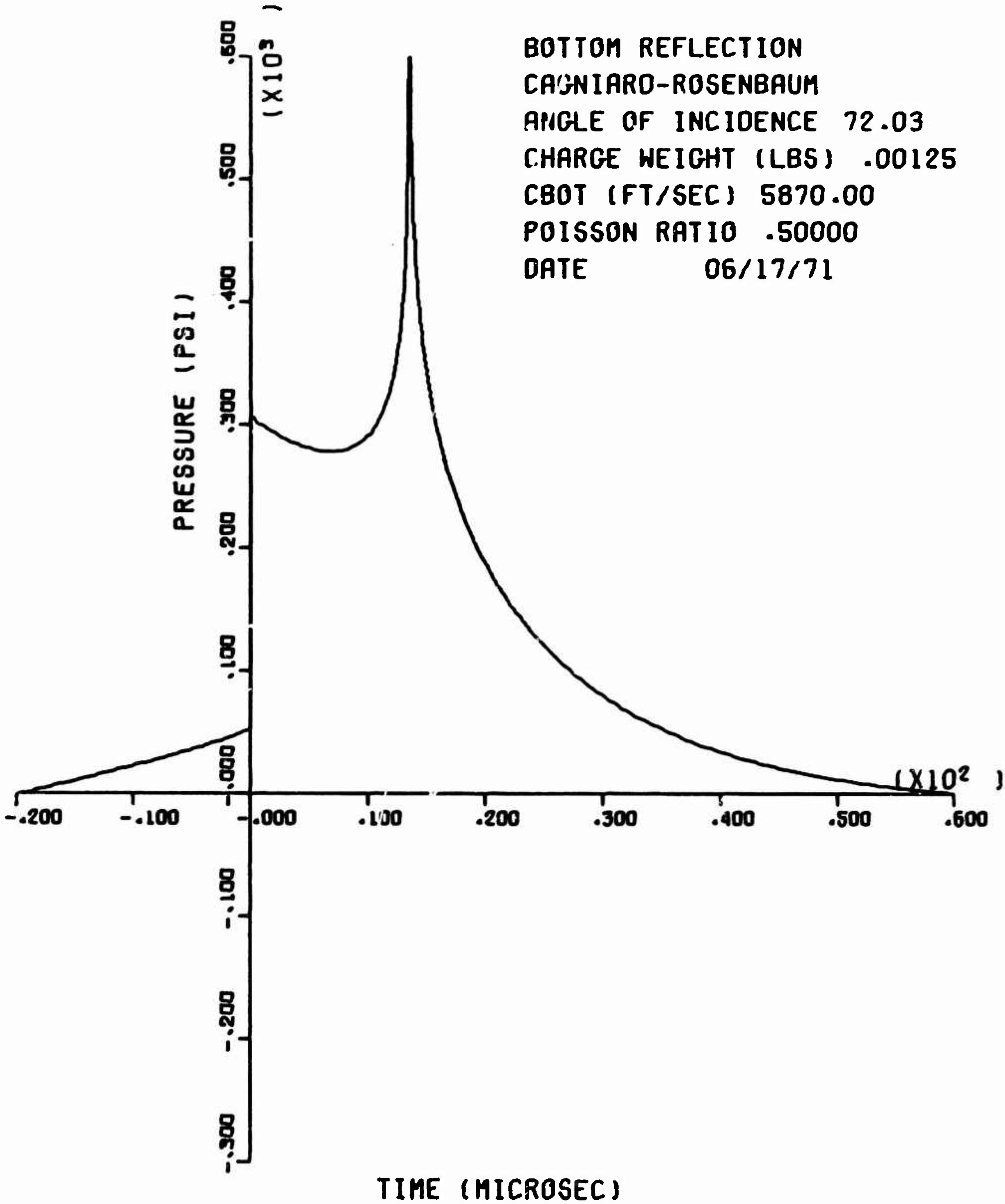

FIG. 2 SAMPLE CALCOMP PLOT OF PRESSURE-TIME HISTORY

APPENDIX C

TWO SPECIAL INPUT OPTIONS

Two special input options for altering the input geometry are provided in the code BOTREF using the variables THOVAL and Z2. The first option allows the programmer to specify an incident angle θ which is expressed as the ratio of the incident angle θ to the critical angle θ_{cr}. This is accomplished by setting THOVAL = $\theta/\theta_{cr} > 0$. If THOVAL ≤ 0, this option is ignored. The programmer also must supply the water depth H, the horizontal range r, and the gauge depth d_g. If possible, the code calculates the required charge depth d keeping d_g fixed. Otherwise, d is set to H, and a new value of d_g is determined. Thus this option permits the user to calculate bottom reflections for a range of incident angles without first having to determine the exact geometry that is required.

The second option using Z2 > 0 provides an alternative means of specifying the reflection geometry. The arrival time Z2 (in microseconds) of the bottom reflected wave after the direct wave is exceedingly sensitive to the geometry which often cannot be measured with the necessary accuracy. This time, which can be accurately measured, provides the means which can be used to correct the input geometry. The geometry is changed by altering d and d_g and holding r fixed so that the incident angle θ and the bottom reflected slant range R_r are unchanged. Typically, the direct and reflected pulses are only slightly altered, but the change in their sum may be significant.